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INVESTIGATION OF COAXIAL JET NOISE AND INLET CHOKING USING AN F-111A AIRPLANE

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16. Abstract

Measurements of engine noise generated by an F-111A airplane positioned on a thrust-measuring platform were made at angles of 0° to 160° from the aircraft heading. Sound power levels, power spectra, and directivity patterns are presented for jet exit velocities between 79 meters per second and 730 meters per second (260 feet per second and 2400 feet per second).

The test results indicate that the total acoustic power was proportional to the eighth power of the core jet velocity for core exhaust velocities greater than 300 meters per second (985 feet per second) and that little or no mixing of the core and fan streams occurred.

The maximum sideline noise was most accurately predicted by using the average jet velocity for velocities above 300 meters per second (985 feet per second).

The acoustic power spectrum was essentially the same for the single jet flow of afterburner operation and the coaxial flow of the nonafterburning condition.

By varying the inlet geometry and cowl position, reductions in the sound pressure level of the blade passing frequency on the order of 15 decibels to 25 decibels were observed for inlet Mach numbers of 0.8 to 0.9.

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INTRODUCTION

The introduction of a large number of jet aircraft into commercial operation has created a significant noise problem in communities near airports. Initially, the major noise source associated with turbojet aircraft was the jet exhausts of the engines; however, with the development and introduction of the turbofan engine, both jets and fans became sources of objectionable noise.

This problem has emphasized the need for a fundamental understanding of noise-generating mechanisms so that methods may be found to significantly reduce aircraft noise. It has been suggested (refs. 1 and 2) that coaxial jet flows produce less noise than a simple circular jet flow of equivalent thrust. The NASA Flight Research Center used an F-111A airplane to study the parameters that influence aircraft noise. This report presents the results of noise measurements made around the airplane while it was positioned on a thrust-measuring platform at Edwards Air Force Base, Calif. During the investigation, the influence of coaxial jet flows on the noise was analyzed, and the results were compared with information in reference 2. In addition, the effect of two side-by-side engines on the radiated noise was examined. The variable geometry of the F-111A inlet was used to study the effectiveness and practicality of choking an aircraft inlet to reduce forward-radiated fan noise.

SYMBOLS

Physical constants in this report are given in the International System of Units (SI) and parenthetically in U.S. Customary Units. The measurements were taken and the calculations were performed in U.S. Customary Units. Factors relating the two systems are presented in reference 3.

D_e	effective jet diameter, m (ft)
f	frequency, Hz
L_W	sound power level, dB (ref. 1×10^{-12} watts)
M_c	Mach number at compressor face

M_i	Mach number at inlet
OASPL	overall sound pressure level (20 to 11,000 Hz), dB (ref. 0.00002 N/m^2)
V_a	average velocity of the jet at the primary nozzle, m/sec (ft/sec)
V_c	velocity of the jet core at the primary nozzle, m/sec (ft/sec)
z	engine separation distance, m (ft)
ΔdB	measured minus calculated OASPL, dB
θ	angle from aircraft heading, deg

TEST AIRPLANE

The supersonic F-111A airplane (fig. 1) has variable-sweep, high-mounted wings and is powered by two TF30 afterburning turbofan engines mounted side by side in the aft fuselage. The TF30 engine is a low-bypass-ratio engine in the 80,000-newton (18,000-pound) thrust class. It is equipped with an afterburner and an aerodynamically actuated blow-in-door ejector. As shown in figure 2, the fan bypass air exits into the afterburner section to form a coaxial stream with the turbine exhaust. At military power settings and below, the primary nozzle contracts as shown; for afterburner operation, the nozzle expands. For nonafterburning operation, the nozzle causes the flow to converge (vena contracta) so that an effective nozzle area is achieved at some point downstream of the primary nozzle. This effective area was determined experimentally by the engine manufacturer and was used in the calculations in this report.

The air inlet for one of the TF30 engines is shown in figure 3. The one-quarter-circle, external-compression inlet is mounted in the wing root area. The geometry of the inlet can be varied by moving the translating spike forward and rearward, changing the angle of the second conical ramp, and opening the translating cowl. In the normal configuration for static and low-speed operation, the second conical ramp is collapsed and the translating cowl slot is opened.

A more complete description of the F-111A airplane and engines is presented in reference 4.

INSTRUMENTATION AND DATA REDUCTION

Engine and Inlet Instrumentation

Extensive engine and inlet instrumentation was installed in the test airplane to investigate inlet dynamics, airplane performance, and in-flight thrust calculation methods. A detailed description of the instrumentation is included in reference 4.

The engine and inlet data were recorded on board the airplane. Calculated velocities were obtained from the thrust calculation program used in the study of reference 4. The accuracy of these velocities and the exhaust nozzle areas is estimated to be ±3 percent.

Acoustic Instrumentation

Microphones were positioned around the test airplane as illustrated in figure 4. These microphones were placed on a 76.4-meter (250-foot) radius with the origin on the airplane centerline midway between the inlets and exhaust nozzles. The airplane heading is defined as 0°, and the microphones were positioned in 10° increments from 0° to 160° at the height of the engine centerline, 1.9 meters (6.3 feet). The height of each microphone above the ground was as follows:

Angle from airplane nose, deg	Microphone height, m (ft)
0	1.3 (4.3)
10	1.3 (4.3)
20	1.6 (5.1)
30	1.8 (6.1)
40	2.4 (8.0)
50	2.8 (9.2)
60	3.0 (10.0)
70	3.1 (10.3)
80	3.3 (10.9)
90	3.6 (11.8)
100	3.6 (11.9)
110	3.5 (11.6)
120	3.4 (11.0)
130	2.8 (9.2)
140	2.6 (8.6)
150	2.2 (7.2)
160	2.1 (7.0)

Because of the large number of simultaneous measurements required for these tests, two different available microphone systems were used. A block diagram of the acoustic data acquisition system used for the microphones in the 0° to 110° positions is shown in figure 5(a). Each microphone was connected to an oscillator-detector circuit by a low-impedance coaxial cable to form a tuned radio frequency circuit. The output of each detector circuit was amplified and recorded on a magnetic-tape recorder.

A block diagram of the data acquisition system used at microphone positions 120° to 160° is shown in figure 5(b). The data signal from each microphone was driven through a cable by an amplifier to an instrument van. Electrical power for each microphone and line-driving amplifier was supplied by batteries through an inverter. The cable from each microphone was terminated at the van with a line-isolation transformer, and the signal was routed to an amplifier and recorded on a magnetic-tape recorder. Time of day from a time-code receiver was also recorded on both systems to enable correlation with the engine data recorded on board the airplane.

The acoustic data acquisition systems were calibrated in a laboratory over a frequency range from 20 hertz to 11,000 hertz before and after each test. The systems were acoustically calibrated for level and linearity on the day of a test.

Acoustic Data Reduction

A block diagram of the system used to reduce the acoustic data is shown in figure 6. A magnetic-tape playback unit recovered the data signal which was routed to a one-third-octave-band analyzer. Parallel analog outputs of one-third-octave-band data were amplified and recorded on strip-chart recorders. An effective averaging time of 10 seconds was used in analyzing the data.

The reduced acoustic data were corrected for data acquisition and data reduction system response, angle-of-sound impingement on the microphone, and background noise. The data reduction system was an averaging system, and the measured sound levels are considered to be accurate to ±1 decibel.

A narrow-band (20-hertz) analysis was performed on the noise data from one microphone position to evaluate the effect of choking on the radiated inlet noise. Inasmuch as the narrow-band analysis was used to evaluate the reduction in the blade passing frequency sound pressure level, no absolute error was estimated. The averaging time was such that the 90-percent statistical confidence interval was ±1 decibel.

The total sound power was calculated by using the method outlined in reference 5. The basic assumptions of this method are that the measurements are made in the far field, the sound is radiated through a hemisphere, and the sound field is symmetric about the airplane's longitudinal axis. Even though the last microphone was positioned at 160°, in the sound power calculation it was assumed that the sound pressure level was constant between 160° and 180°.

TEST DESCRIPTION

Operational Procedures

The F-111A airplane was positioned on the Edwards Air Force Base static-thrust calibration facility (ref. 6), and thrust and noise were measured concurrently. The tests consisted of a series of noise, thrust, and engine parameter measurements for several engine power settings ranging from idle to maximum afterburner during one- and two-engine operation. The cowls were open except in the choking tests. After engine speed and thrust were stabilized at each power setting, approximately 1 minute of acoustic data and 15 seconds of onboard data were recorded.

Additional tests were performed on the left engine in which the inlet geometry was changed by closing the cowl and varying the inlet area to cause choked inlet flow. The inlet area was varied by translating the movable spike and expanding the inlet cone.

Engine speed and thrust were stabilized before the acoustic, thrust, and onboard data were recorded.

Environmental Conditions

The terrain surrounding the thrust calibration stand was clear of obstructions, with a concrete taxiway directly in front of the test airplane. During the tests, winds were calm, the temperature was 24.4° C (76° F), and the relative humidity was 22 percent.

RESULTS AND DISCUSSION

A limited amount of acoustic data for an F-111A airplane was presented in reference 7. An attempt to reconcile discrepancies between these data and the data presented herein was unsuccessful because of the unavailability of engine performance and jet exhaust flow measurements in reference 7.

Noise Levels and Spectra

The basic acoustic power and spectral characteristics of the F-111A airplane are presented in figures 7(a) and 7(b) for several engine power settings. At the maximum afterburner and military power settings, the spectra peak between 100 hertz and 200 hertz and decrease smoothly in amplitude on both sides of the peak. This is typical of the spectra of a turbojet engine. At the two lowest engine power settings, the spectra are characterized by a peak at the fundamental fan blade passing frequency (2000 hertz to 2500 hertz). The trend of the spectra for one- and two-engine operation is similar; only the level is different at the same power setting. The acoustic measurements made during these tests are tabulated in tables 1 and 2 for one- and two-engine operation, respectively. Also included are the perceived noise levels (ref. 8) for each engine power setting at 10° angular increments around the airplane. The sound power level, L_W, for each one-third-octave band and the overall sound power level are tabulated for each engine power setting.

The directional characteristics of the F-111A noise in terms of overall sound pressure level are shown in figure 8. For one-engine operation at intermediate power settings (fig. 8(a)), the maximum measured OASPL occurs only 20° from the jet axis as opposed to the usual 45° for a pure turbojet with a standard circular exhaust nozzle. For two-engine operation at intermediate power settings (fig. 8(b)), the maximum OASPL shifts away from the jet axis to an angle of 30° to 40° for power settings above 45-percent rpm. This indicates that the exhaust flows are aerodynamically interfering with each other and modifying the noise directivity.

The total acoustic power radiated by a subsonic jet is proportional to the eighth power of the jet velocity, as shown by Lighthill in reference 9. It should be noted that the F-111A exhaust velocity was subsonic, with respect to local flow conditions, for all engine power settings and that coaxial flow existed for nonafterburning power settings. Presented in figure 9 is the total sound power radiated by the F-111A airplane as a function of core jet velocity, which was determined from measured pressures and calculated temperatures (ref. 4). The two-engine data were normalized to one-engine data by subtracting 5 log N, where N is the number of engines. The figure shows that the sound power correlates with the core jet velocity for velocities greater than 300 meters per second (985 feet per second). In this region, the sound power is a function of the core jet velocity to the eighth power (V_c^8). The sound power estimated by using the empirical constant determined in reference 10 is shown as a dashed line. The agreement of the estimated and measured data is excellent. Using the thrust calculation program of reference 4, an average jet velocity was calculated on the basis of measured pressure ratios and calculated temperatures for the combined core and fan exhaust streams. The complete mixing of the core and fan airflows results in a mixed flow or average jet velocity about 20 percent lower than the core jet velocity. A comparison of the sound power with the mixed-flow velocity shows a disagreement of 8 decibels between the present data and the data of reference 10. Thus the close correlation between the sound power and the eighth power of the core jet velocity indicates little or no mixing of the bypass and core exhaust streams by the time the flow passes through the primary nozzle. This is supported by the study of reference 11, which shows that for a length-to-diameter ratio of 2, less than 35-percent mixing was achieved with a convergent nozzle, which is similar to the F-111A engine configuration.

The deviation of the sound power from the V_c^8 dependence for velocities less than 300 meters per second (985 feet per second) is believed to be caused by afterburning rings, flameholders, and fuel injectors positioned in the flow path ahead of the primary nozzle. At low velocities the noise generated by the flow interacting with the mechanical hardware is greater than the self noise or shear noise generated in the turbulent flow. A more complete discussion of these effects is included in reference 12. Also, the fan-generated noise becomes significant at the low engine power settings.

The maximum measured overall sound pressure level is compared with the maximum overall sound pressure level predicted by the SAE method (ref. 13) on a 61-meter (200-foot) sideline in figure 10. The best correlation occurs for an angle of 140° from the aircraft heading, using the average jet velocity in the SAE method rather than the core jet velocity. This is not surprising, since this method is an empirical procedure based on average jet velocity.

Parallel Coplanar Jet Noise

To investigate the possibility that the noise in the horizontal plane could be reduced by operating two engines side by side, the single-engine noise data were scaled up to the exit area of the two-engine data. The difference between the scaled one-engine peak sound pressure levels and the measured two-engine peak sound pressure levels was defined as the noise reduction. This noise reduction is plotted versus dimensionless separation distance in figure 11. The poor agreement between the data of the present tests and the data of reference 14 indicates that the noise reduction may not be a function of geometry alone. The flow variables such as velocity, temperature, and density probably enter into the amount of noise reduction this configuration can provide in the horizontal plane.

Coaxial Jet Noise

The normalized power spectra for one- and two-engine operation at power settings of 83-percent rpm, military, and maximum afterburner are shown by the shaded region in figure 12. For the 83-percent-rpm and military power settings, the ratio of fan air velocity to core jet velocity is 0.63. At maximum afterburning the jet velocity is approximately constant across the nozzle, which produces a simple jet stream. No trends or significant differences were observed in the spectra for afterburning and nonafterburning power settings. The fact that the spectral points for all power settings are similar indicates that there are no discernible differences in the sound power spectrum of coaxial and simple jet flows for this configuration. The solid line represents the average spectrum for a large number of model jets and full-scale engines (ref. 5). The measured spectrum is somewhat lower than the average spectrum at the higher frequencies; however, this same trend was observed in other full-scale turbojet engine tests (ref. 15).

A recent study (ref. 2) was made with coaxial model jets to assess the effect of coaxial jet flow on engine noise. A heated central jet was used to obtain a range of fan-jet-velocity to core-jet-velocity ratio between 0.33 and 0.67. For a velocity ratio of 0.67 it was observed that the acoustic energy was reduced in the high-frequency portion of the spectrum and increased at low frequencies. Any such redistribution of acoustic energy would be desirable, because psychological measures of annoyance such as perceived noise level (PNdB) are weighted most heavily at high frequencies. The data from the F-111A tests, for which the ratio of fan-to-core airflow velocity was 0.63, indicate that a similar redistribution of acoustic energy did not occur in the TF30 noise spectrum.

Inlet Choking

It has been known for some time that choking the inlet of an aircraft is an effective method of suppressing fan noise (refs. 16 and 17). The variable-geometry feature of the F-111A airplane was used in these tests to vary the inlet Mach number so that the effect of inlet flow velocity on the radiated noise could be investigated. Figure 13 shows the reduction in the sound pressure level of the blade passing frequency as a function of inlet Mach number. These data were analyzed by using the 20-hertz bandwidth filter described previously. Figure 13(a) shows the noise reduction observed at a point directly ahead of the airplane at a distance of 76.4 meters (250 feet) with the cowl closed. The curve represents the following empirical relationship from reference 18:

$$\text{Reduction in sound pressure level} = 20 \log_{10} \frac{M_i}{M_c} \left(\frac{1 - M_i}{1 - M_c} \right)^2$$

where M_i is the Mach number at the inlet and M_c is the Mach number at the compressor face (approximately 0.3 for these tests). This relationship seems to predict the general trend of the noise reduction, although there is considerable scatter in the data.

The closed-cowl tests show that reductions of 15 decibels to 25 decibels in blade passing frequency sound pressure level are possible for average inlet Mach numbers of 0.8 to 0.9.

The noise reduction observed with the cowl open is shown in figure 13(b). The noise is reduced significantly at Mach numbers of 0.6 to 0.7 because the Mach numbers were measured in the inlet forward of the cowl opening. This noise reduction indicates a higher velocity flow region somewhere downstream of the cowl opening comparable to the cowl-closed condition.

CONCLUSIONS

Measurements of engine noise generated by an F-111A airplane positioned on a thrust-measuring platform showed that:

1. The total acoustic power was proportional to the eighth power of the core jet velocity for core exhaust velocities greater than 300 meters per second (985 feet per second), which implies little or no internal mixing of the bypass and core airflows.

2. The maximum sideline sound pressure level was best estimated by using the average jet velocity.

3. The acoustic power spectrum did not change between the single jet flow and the coaxial jet flow for a fan-to-core-velocity ratio of 0.63.

4. Reductions of 15 decibels to 25 decibels in blade passing frequency sound pressure level are possible for average inlet Mach numbers of 0.8 to 0.9.

Flight Research Center
National Aeronautics and Space Administration
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TABLE 1. - ACOUSTIC MEASUREMENTS AND COMPUTATIONS FOR ONE-ENGINE OPERATION

(a) Maximum afterburner

One-third-octave-band center frequency, Hz	θ, deg																	L_w, dB
	0	10	20	30	40	50	60	70	80	90	100	110	120	130	140	150	160	
	Sound pressure level, dB (ref. 0.00002 N/m^2)																	
50	92.4	91.9	93.4	94.9	95.7	95.7	93.4	93.9	97.9	99.9	102.6	106.7	110.9	114.9	116.9	114.4	108.6	154.5
63	93.9	93.4	94.4	95.9	96.2	96.4	93.9	94.4	98.6	100.9	103.1	107.7	112.7	117.7	118.9	114.9	110.7	156.4
80	95.7	95.9	97.9	98.4	97.9	99.4	96.2	96.4	100.6	101.9	104.4	109.2	115.2	120.2	121.2	116.4	111.9	158.6
100	96.6	98.6	101.7	100.7	99.7	99.9	96.9	96.1	100.9	101.9	105.1	108.1	115.2	122.4	122.9	118.7	113.4	160.3
125	96.4	97.4	99.9	98.1	98.6	99.1	96.1	96.9	101.6	102.9	105.6	108.1	113.2	121.9	123.2	119.4	113.4	160.2
160	95.9	97.1	98.4	98.1	97.9	98.1	96.1	96.6	100.6	101.6	105.9	108.9	114.4	117.9	121.9	118.7	112.9	158.5
200	98.4	98.1	98.1	97.9	98.1	99.6	97.1	96.6	99.6	102.9	106.4	109.9	117.4	118.1	119.1	117.6	112.4	158.0
250	98.1	98.4	99.4	97.9	98.6	99.6	95.4	96.6	100.4	104.1	106.9	109.9	118.7	120.9	118.9	116.1	110.9	158.9
315	94.9	96.1	99.4	99.1	97.6	98.6	95.1	95.9	98.9	103.6	106.1	109.7	115.9	121.4	118.4	112.6	109.6	158.2
400	93.4	95.6	98.2	98.1	98.4	98.4	96.4	94.9	98.4	102.4	105.9	109.4	113.9	117.9	115.6	111.1	106.6	155.5
500	93.1	95.6	98.9	97.4	99.1	98.1	94.9	94.9	97.9	101.9	105.6	109.9	113.7	117.7	115.6	110.9	106.4	155.4
630	92.4	96.4	100.4	97.2	97.7	96.9	94.1	95.7	99.4	100.6	104.4	108.2	111.7	114.9	111.9	108.4	101.9	152.9
800	90.4	95.9	99.4	97.2	97.7	97.4	95.2	96.2	99.6	100.6	103.9	107.4	110.7	114.2	111.1	105.9	100.1	152.0
1,000	89.9	94.4	97.2	95.2	94.4	95.4	93.4	94.1	98.9	99.4	101.9	105.4	107.9	112.9	108.6	103.6	97.6	150.1
1,250	89.1	92.9	96.2	94.4	94.1	94.9	92.4	92.9	96.9	98.4	100.6	103.4	106.4	109.4	106.4	100.4	94.9	147.7
1,600	87.6	89.6	93.7	93.6	92.9	92.4	90.6	90.6	94.9	96.9	99.4	100.4	104.4	110.2	105.4	98.6	94.4	147.0
2,000	86.6	88.9	90.9	93.6	92.1	91.6	91.0	91.1	95.9	97.9	98.4	99.7	102.9	106.4	103.4	95.6	91.9	144.8
2,500	84.6	88.1	89.6	92.1	91.3	91.3	90.8	90.6	97.1	97.6	96.8	97.9	101.9	105.1	102.4	93.9	89.9	143.7
3,150	82.6	86.4	88.9	90.4	90.9	90.2	88.6	91.4	96.6	98.4	97.2	95.9	101.1	103.4	102.1	91.6	86.4	142.9
4,000	81.2	84.1	84.9	87.7	86.4	87.2	86.2	86.7	93.9	94.9	94.5	95.0	98.9	101.6	97.6	85.6	85.4	140.3
5,000	79.1	81.4	81.0	84.8	82.8	84.1	83.1	82.8	90.1	91.1	92.3	93.0	96.4	100.9	94.4	84.9	81.4	138.2
6,300	77.4	78.5	77.2	81.4	81.1	81.4	79.8	79.2	85.3	86.5	87.9	89.7	94.1	98.9	91.9	82.6	78.6	135.6
8,000	76.3	76.9	73.8	78.5	78.9	79.0	76.3	76.7	80.1	84.5	83.9	85.6	92.9	99.1	90.1	79.6	75.9	134.7
10,000	70.7	70.5	66.2	71.2	72.2	71.6	69.0	69.2	74.7	77.3	77.6	81.2	90.4	95.4	88.1	76.6	75.9	131.2
	OASPL, dB																	
------	106.4	108.4	110.7	109.9	109.7	109.7	107.7	107.2	111.6	114.2	116.9	120.2	126.2	130.7	130.9	127.2	121.9	[a]169.0
	Perceived noise level, PNdB																	
------	113.5	115.6	117.8	118.3	118.1	118.1	116.4	117.2	122.0	123.9	124.9	127.3	132.7	136.7	134.5	130.0	125.1	-----

[a]Overall L_w.

TABLE 1. - ACOUSTIC MEASUREMENTS AND COMPUTATIONS FOR ONE-ENGINE OPERATION - Continued

(b) Military power

One-third-octave-band center frequency, Hz	θ, deg																	L_w, dB
	0	10	20	30	40	50	60	70	80	90	100	110	120	130	140	150	160	
	Sound pressure level, dB (ref. 0.00002 N/m^2)																	
50	77.4	77.9	80.2	80.7	81.2	81.2	82.7	83.2	84.4	85.6	86.4	88.4	91.1	98.9	102.4	105.4	104.4	142.0
63	79.2	79.9	83.4	84.4	84.9	84.9	85.4	86.7	87.1	88.4	88.9	91.1	94.6	102.4	105.9	108.9	106.4	145.1
80	82.1	83.4	88.4	89.2	89.4	90.2	89.9	89.7	90.7	90.9	92.2	94.1	97.9	105.7	110.2	112.7	109.2	148.8
100	85.9	89.4	93.1	92.7	92.1	91.9	91.4	90.6	90.9	92.1	94.9	96.9	98.9	106.7	111.9	115.2	110.9	150.7
125	86.9	89.1	92.4	90.4	90.9	90.6	90.1	90.6	92.6	93.9	96.1	98.6	100.7	107.4	110.9	115.9	112.2	151.2
160	88.1	89.9	91.9	90.9	89.9	90.6	90.1	92.1	92.1	92.4	96.7	98.9	102.9	109.4	109.9	115.9	114.2	151.8
200	93.4	94.1	92.1	91.4	93.6	96.4	94.4	92.9	93.6	93.9	97.4	100.9	103.1	111.7	112.9	112.9	116.2	152.7
250	92.9	93.6	96.1	93.9	97.1	95.1	95.1	96.9	97.4	96.6	98.9	100.6	103.4	110.9	114.9	111.6	115.4	152.7
315	88.9	91.9	95.4	93.7	93.9	93.7	96.7	96.2	95.9	96.2	98.7	99.7	103.9	110.9	113.4	112.9	114.9	152.3
400	89.6	91.4	93.9	92.9	93.4	93.1	93.9	91.4	92.9	94.4	97.4	99.1	101.7	108.9	109.1	111.7	110.1	149.3
500	89.4	90.9	94.7	91.9	94.2	92.9	91.6	91.4	90.4	94.2	97.4	99.7	101.4	108.4	109.1	111.4	110.1	149.1
630	87.4	90.9	94.2	91.7	91.7	89.9	91.2	91.2	92.2	91.9	94.4	97.4	100.7	105.7	106.2	108.7	103.4	146.0
800	84.9	89.9	92.7	89.7	89.4	89.5	89.9	90.2	91.4	91.4	93.2	96.9	100.4	105.2	105.4	106.7	103.1	145.0
1,000	83.9	87.9	90.2	87.6	86.9	88.1	87.4	88.7	89.7	89.4	91.7	94.9	97.9	104.2	103.4	104.1	101.1	143.2
1,250	83.1	86.9	87.6	86.4	86.9	86.9	85.9	86.1	87.1	88.7	90.6	91.9	95.9	101.2	101.1	101.6	97.9	140.6
1,600	81.4	83.6	85.6	85.4	85.1	84.9	84.9	84.6	84.9	86.6	89.1	89.6	93.4	100.7	99.9	98.9	95.4	139.1
2,000	79.9	82.6	84.9	85.6	85.1	84.6	85.6	85.4	86.1	87.1	88.1	89.7	91.9	96.9	97.1	95.1	92.4	136.5
2,500	80.1	82.6	84.3	84.3	84.6	84.1	84.8	84.6	86.6	87.1	87.1	88.1	91.1	95.6	95.4	90.9	89.4	135.0
3,150	80.1	82.6	84.4	83.1	83.9	82.4	82.9	84.9	85.9	87.4	87.4	86.9	89.1	92.9	93.9	87.4	84.6	133.3
4,000	79.7	81.9	81.4	81.4	80.9	81.0	82.0	81.4	83.9	83.7	85.2	86.5	86.4	91.1	86.6	81.1	82.9	130.4
5,000	78.1	79.6	78.2	79.8	79.1	79.1	79.9	79.3	80.6	81.1	83.6	85.0	84.4	88.9	83.1	82.4	79.6	128.3
6,300	76.9	77.3	75.2	78.1	78.1	77.6	78.3	77.7	77.0	77.5	80.4	81.9	82.6	85.1	82.4	81.1	77.9	125.7
8,000	75.9	75.4	71.8	75.0	75.9	75.2	76.3	75.7	71.9	73.5	75.9	76.9	80.1	82.1	81.1	77.9	75.9	122.7
10,000	70.0	68.5	64.5	68.7	70.2	69.3	69.5	69.0	66.2	66.3	69.8	70.7	76.4	77.6	77.1	74.4	73.9	117.9
	OASPL, dB																	
------	100.4	102.2	104.4	102.9	103.7	103.4	103.7	103.2	104.4	104.9	107.2	109.7	112.2	119.2	121.7	123.7	123.2	[a]161.2
	Perceived noise level, PNdB																	
------	108.2	110.4	112.1	111.3	111.9	111.4	112.1	112.1	112.8	113.8	115.3	117.1	119.9	126.2	127.7	127.8	127.4	-----

[a]Overall L_w.

TABLE 1. - ACOUSTIC MEASUREMENTS AND COMPUTATIONS FOR ONE-ENGINE OPERATION - Continued

(c) 83-percent rpm

One-third-octave-band center frequency, Hz	θ, deg																	I_W, dB
	0	10	20	30	40	50	60	70	80	90	100	110	120	130	140	150	160	
	Sound pressure level, dB (ref. 0.00002 N/m^2)																	
50	74.4	75.4	77.2	79.2	80.4	79.9	81.2	81.9	82.4	82.9	83.9	86.6	92.7	95.9	98.1	101.9	101.9	139.0
63	76.9	77.6	81.2	82.4	83.7	83.7	84.2	85.4	85.4	86.4	86.9	89.4	94.9	99.2	102.4	105.9	104.7	142.5
80	80.1	81.9	86.2	87.7	88.2	88.7	88.2	87.4	87.9	88.2	89.4	90.9	96.4	100.9	104.9	108.9	107.4	145.1
100	83.9	87.1	91.2	90.9	90.1	90.1	89.9	87.6	88.1	90.1	91.9	94.2	95.9	101.7	106.2	111.2	108.4	146.7
125	84.9	87.6	90.9	88.9	88.9	88.4	86.9	88.4	90.1	91.4	93.4	95.9	97.4	102.4	105.4	111.9	109.9	147.4
160	85.9	87.6	88.4	87.9	86.9	88.4	88.9	89.6	89.4	89.1	93.1	95.4	97.4	103.4	104.4	110.4	110.7	147.0
200	92.4	93.4	90.6	88.9	91.6	95.1	95.1	91.9	92.9	91.9	95.1	96.6	98.4	104.6	106.6	106.1	112.7	147.8
250	91.1	91.6	92.6	90.1	94.4	92.1	92.1	93.9	93.4	92.9	95.4	96.4	99.6	104.4	107.6	104.9	109.4	146.5
315	87.1	89.1	90.9	89.4	90.1	90.1	93.1	91.9	92.4	91.7	94.2	94.9	98.9	104.2	104.7	105.4	108.9	145.6
400	86.9	88.9	90.1	89.1	88.9	89.1	90.4	87.1	88.6	89.9	93.9	95.4	96.7	102.2	101.9	102.9	104.6	142.8
500	86.9	88.6	90.6	88.4	89.6	88.9	88.1	87.4	86.1	89.6	93.7	95.9	96.2	101.9	101.6	102.4	104.4	142.5
630	85.9	87.9	90.6	87.1	86.9	85.6	85.4	85.9	86.7	86.9	89.2	91.9	94.9	99.4	98.6	99.4	98.9	139.3
800	82.9	86.4	88.9	85.1	84.4	85.1	84.6	85.4	85.9	86.2	87.6	90.9	94.4	99.2	97.9	97.6	96.1	138.2
1,000	82.4	85.1	86.9	83.4	82.4	83.1	82.9	82.9	84.1	84.4	86.1	88.9	91.9	97.9	95.9	95.1	91.9	136.2
1,250	82.9	86.1	85.6	83.6	82.9	82.6	81.9	80.9	81.9	83.6	84.6	86.4	90.1	94.6	93.9	92.4	88.9	133.8
1,600	83.9	86.6	85.1	85.6	84.9	84.6	83.4	82.6	81.4	82.1	83.4	83.9	87.9	93.7	92.9	90.1	89.1	132.9
2,000	81.9	84.9	84.7	85.4	85.6	84.9	85.4	84.1	83.4	84.1	82.4	83.4	86.6	90.4	90.1	86.1	85.9	131.3
2,500	80.6	83.1	85.1	84.1	84.3	84.1	83.8	82.6	83.1	83.6	81.3	81.9	85.6	88.9	88.9	83.4	82.4	130.1
3,150	85.6	87.4	90.4	88.1	86.9	84.7	84.1	84.4	83.4	84.6	81.9	80.9	84.1	86.4	87.9	81.6	79.9	130.5
4,000	85.5	88.4	88.0	88.2	85.7	84.7	84.2	82.7	81.9	81.9	81.0	81.0	81.6	85.1	82.1	77.1	80.6	129.1
5,000	80.6	84.9	81.3	83.6	81.1	80.6	80.6	78.6	78.3	78.6	78.6	79.0	79.9	82.6	78.4	77.9	78.1	125.5
6,300	77.9	80.3	76.2	79.9	78.9	77.6	77.3	75.5	74.5	74.5	74.9	75.7	77.6	78.9	76.4	76.6	76.1	122.3
8,000	75.9	76.9	71.8	77.0	75.9	75.0	74.3	73.7	69.9	71.5	71.1	70.9	74.6	74.6	73.6	72.4	71.9	119.0
10,000	69.0	69.3	63.5	69.0	68.9	67.3	66.8	66.7	63.7	63.8	65.1	65.4	70.9	70.6	70.9	69.1	70.4	113.4
	OASPL, dB																	
------	99.2	100.9	101.9	100.7	101.2	101.2	101.7	100.2	100.9	101.4	104.9	105.7	107.7	113.2	114.9	118.2	118.9	[a]156.0
	Perceived noise level, PNdB																	
------	110.0	112.5	113.5	112.3	111.7	110.8	110.6	110.1	109.7	110.5	110.9	112.5	115.0	119.8	120.8	121.2	122.9	-----

[a]Overall I_W.

TABLE 1. - ACOUSTIC MEASUREMENTS AND COMPUTATIONS FOR ONE-ENGINE OPERATION - Continued

(d) 59-percent rpm

One-third-octave-band center frequency, Hz	θ, deg																	L_W, dB
	0	10	20	30	40	50	60	70	80	90	100	110	120	130	140	150	160	
	Sound pressure level, dB (ref. 0.00002 N/m^2)																	
50	70.9	73.4	76.9	77.2	77.7	76.4	77.4	78.4	79.4	79.1	78.6	80.4	80.9	85.4	85.9	88.9	88.4	127.7
63	72.4	74.6	78.9	79.7	80.4	79.9	79.9	80.7	80.7	81.4	81.2	82.4	82.9	87.4	87.7	90.4	90.7	129.7
80	75.9	78.4	83.4	84.7	84.7	85.2	84.4	83.2	83.7	83.4	84.2	84.9	85.2	88.4	88.9	91.7	91.4	131.7
100	78.1	81.1	84.9	84.9	84.6	84.4	83.4	82.1	81.6	83.1	85.2	87.2	86.7	89.7	90.2	94.2	94.2	133.1
125	79.9	82.9	86.4	83.1	83.9	82.1	80.6	82.4	84.4	86.7	88.4	89.9	89.9	91.4	89.4	92.4	93.2	133.6
160	81.9	84.6	87.4	84.9	80.9	82.6	84.6	87.4	85.7	85.9	87.7	87.4	87.2	90.2	89.4	90.4	92.9	133.0
200	80.1	84.4	83.9	81.9	78.1	82.4	83.9	82.9	81.9	81.9	83.1	84.6	86.1	91.6	91.1	87.1	90.1	131.5
250	79.1	80.1	82.6	79.4	81.9	80.1	81.1	82.9	83.9	82.9	83.9	83.4	85.4	89.4	89.9	86.6	86.6	130.3
315	77.9	81.4	81.6	81.4	81.4	80.1	81.9	79.4	80.4	79.6	81.1	82.6	85.2	88.9	86.4	85.9	83.6	128.8
400	78.4	80.4	79.4	78.1	77.1	77.1	77.9	74.4	76.4	76.9	78.1	79.6	82.1	85.9	84.1	83.4	80.9	125.8
500	78.1	80.1	79.9	77.4	77.9	76.9	75.6	74.4	73.6	76.6	78.1	80.1	81.9	85.6	84.1	83.1	80.6	125.5
630	78.4	79.9	80.4	76.1	75.9	74.4	73.4	72.6	73.6	73.1	75.4	76.4	78.4	81.1	80.6	80.1	77.4	122.5
800	77.4	77.6	79.9	75.1	74.1	73.9	73.4	72.4	72.1	72.4	73.1	74.9	76.9	81.4	79.4	77.9	74.9	121.5
1.000	78.6	78.1	79.6	75.4	73.4	73.9	73.6	72.4	70.6	71.1	71.9	73.1	74.6	79.9	77.6	75.1	72.4	120.3
1.250	81.1	81.6	81.6	79.1	79.1	77.1	75.4	73.6	72.9	71.9	71.4	72.1	73.4	77.4	75.9	74.4	72.4	121.2
1.600	83.1	83.6	83.4	83.9	83.1	81.6	80.9	79.1	76.9	74.1	70.9	70.4	72.4	77.6	76.4	74.4	74.1	124.2
2.000	79.6	80.6	82.7	81.9	82.6	81.6	82.1	78.6	77.1	75.4	69.1	69.4	71.9	75.6	75.1	72.1	73.4	123.7
2.500	95.6	97.1	98.4	93.4	93.6	92.1	92.1	88.6	86.4	83.3	77.1	74.9	77.1	81.4	80.6	77.6	77.6	134.9
3.150	89.9	91.9	93.4	89.9	90.7	89.0	88.2	86.9	84.4	83.2	75.9	72.9	75.1	78.1	79.4	74.4	73.9	131.5
4.000	85.5	87.7	86.2	85.7	83.7	81.7	81.0	78.2	76.4	74.4	70.7	70.2	70.6	74.1	72.1	66.4	71.9	124.9
5.000	86.6	86.9	84.3	85.4	82.9	81.7	80.7	77.9	77.1	73.1	70.1	70.2	71.1	72.4	70.1	69.4	69.1	124.3
6.300	80.9	82.6	79.7	82.4	81.2	78.9	78.0	75.7	75.0	71.5	68.9	69.7	71.4	72.6	71.6	70.1	68.9	121.7
8.000	77.4	79.2	74.3	78.5	77.2	74.5	73.9	71.7	68.4	66.2	63.4	63.9	68.1	70.1	69.9	67.6	66.6	117.6
10.000	70.0	70.8	65.2	70.0	69.7	66.8	65.9	64.0	61.7	58.3	56.6	57.7	63.2	65.2	63.6	62.1	61.9	110.2
	OASPL, dB																	
-----	99.7	100.2	101.2	98.7	97.9	97.4	97.2	94.9	94.9	94.7	94.2	95.9	96.7	99.9	99.9	101.4	101.9	[a]143.3
	Perceived noise level, PNdB																	
-----	113.4	115.0	115.8	112.6	112.4	111.0	110.9	108.4	106.8	105.2	101.7	101.3	103.1	106.8	106.0	104.4	104.4	-----

[a]Overall L_W.

TABLE 1. - ACOUSTIC MEASUREMENTS AND COMPUTATIONS FOR ONE-ENGINE OPERATION - Concluded

(e) 45-percent rpm

One-third-octave-band center frequency, Hz	θ, deg																	L_W, dB
	0	10	20	30	40	50	60	70	80	90	100	110	120	130	140	150	160	
	Sound pressure level, dB (ref. 0.00002 N/m^2)																	
50	66.9	68.6	71.9	73.2	74.2	72.7	72.7	72.7	71.9	73.6	73.6	74.4	75.9	78.4	76.4	76.6	75.1	119.9
63	66.9	67.9	70.9	72.4	72.9	70.9	70.4	72.4	70.6	72.4	71.6	72.9	80.9	81.2	77.4	77.7	78.2	121.2
80	66.9	68.1	71.9	72.9	73.4	73.4	72.4	71.7	71.6	72.4	72.1	72.9	76.4	79.6	78.4	78.1	76.9	120.3
100	66.6	70.1	73.6	73.4	72.9	73.9	72.4	70.9	70.1	71.6	73.4	75.4	76.1	78.1	77.6	77.6	76.4	120.0
125	66.1	69.4	72.6	70.4	69.9	70.6	66.9	68.1	70.9	73.1	75.4	77.1	78.4	81.1	78.9	78.4	77.9	121.1
160	63.8	64.6	70.4	71.9	67.6	68.4	66.9	66.4	68.1	68.4	73.1	74.9	76.4	79.6	76.4	74.9	77.1	119.1
200	70.1	72.6	71.9	70.9	66.1	67.4	66.9	66.9	67.9	67.1	71.1	73.1	74.6	79.6	78.1	72.6	77.4	118.8
250	71.6	73.6	72.6	68.1	68.1	67.9	67.9	66.1	66.9	65.6	67.4	69.4	72.4	76.9	76.6	72.1	69.1	116.5
315	71.6	74.4	73.6	71.9	71.6	69.4	70.6	68.1	66.9	67.1	69.6	71.1	72.1	76.4	74.6	74.9	64.4	117.0
400	73.4	75.4	72.4	71.9	70.9	70.4	71.9	67.4	68.6	67.4	68.4	71.4	74.4	77.9	75.9	72.6	69.1	117.8
500	73.1	75.1	72.9	70.9	71.4	69.9	68.6	66.9	64.1	66.9	68.1	71.9	74.1	77.4	75.6	72.4	68.9	117.2
630	73.6	74.9	74.1	72.9	69.6	70.9	69.4	63.9	63.4	66.9	65.1	66.6	67.9	67.9	72.1	70.9	68.9	114.6
800	71.4	72.1	73.1	69.4	69.1	67.9	66.6	64.9	63.4	63.9	62.9	64.6	67.1	69.9	69.9	68.4	65.4	112.9
1,000	73.1	73.6	73.4	70.9	69.1	69.1	68.6	66.4	63.9	63.4	63.6	65.9	67.6	71.6	68.1	67.4	64.6	113.6
1,250	77.4	79.6	77.9	75.1	73.6	72.6	70.6	67.1	66.4	65.1	63.6	65.1	66.1	70.1	68.1	68.4	66.4	116.0
1,600	76.4	76.4	76.1	76.9	75.6	73.4	71.9	69.6	67.4	66.6	61.9	62.6	64.4	70.1	68.6	68.1	67.4	116.4
2,000	89.7	92.7	95.2	92.4	94.4	92.7	90.4	85.2	80.4	83.7	70.4	70.2	70.6	81.4	79.1	79.1	79.1	133.5
2,500	81.6	84.1	84.6	83.6	84.9	83.9	83.9	79.6	77.3	76.3	68.1	66.9	68.4	74.4	74.4	70.9	71.4	125.3
3,150	81.6	84.6	82.9	81.9	81.4	79.9	79.1	77.1	73.6	73.4	67.4	64.9	67.6	70.6	72.6	67.6	66.4	122.3
4,000	82.7	84.9	82.5	84.5	81.9	80.2	79.0	76.2	73.7	70.9	67.5	67.0	67.4	70.6	68.1	61.6	65.9	122.7
5,000	78.6	81.4	77.5	81.1	78.4	77.2	76.4	73.1	71.1	68.8	66.6	67.5	68.9	70.6	68.1	66.4	63.4	119.6
6,300	76.9	78.8	73.0	77.4	76.1	73.4	72.8	69.7	68.0	65.7	63.2	65.2	67.9	69.9	68.9	65.1	61.4	116.6
8,000	72.1	73.2	66.6	72.0	70.9	68.5	67.9	65.7	61.1	60.5	59.1	60.6	65.9	69.6	68.4	62.6	60.6	112.3
10,000	66.2	65.5	57.7	64.2	64.2	61.3	60.8	59.0	55.7	53.8	53.1	54.2	59.9	62.9	61.4	56.6	55.9	105.4
	OASPL, dB																	
-----	92.9	95.1	96.4	94.7	95.4	93.9	92.4	87.9	85.9	86.4	85.1	85.9	84.4	89.1	87.4	86.4	86.6	[a]135.9
	Perceived noise level, PNdB																	
-----	106.6	109.1	109.9	108.4	109.2	107.7	106.0	101.9	98.5	100.0	92.9	93.5	95.3	101.4	99.7	98.2	97.5	-----

[a]Overall L_W.

TABLE 2. - ACOUSTIC MEASUREMENTS AND COMPUTATIONS FOR TWO-ENGINE OPERATION

(a) Maximum afterburner

One-third-octave-band center frequency, Hz	θ, deg																	L_w, dB
	0	10	20	30	40	50	60	70	80	90	100	110	120	130	140	150	160	
	Sound pressure level, dB (ref. 0.00002 N/m^2)																	
50	93.9	94.9	95.9	96.4	97.4	97.7	99.2	99.2	101.7	103.2	104.9	109.7	113.9	117.9	115.9	111.9	107.0	155.7
63	94.9	96.2	97.4	98.2	98.7	99.4	100.7	100.7	102.9	104.7	106.9	110.9	115.2	120.4	116.9	113.4	108.5	157.5
80	97.2	97.9	100.4	100.9	101.4	102.9	103.7	102.9	104.9	105.9	108.4	112.4	118.2	122.4	118.4	116.2	110.0	159.6
100	98.4	99.9	102.9	103.4	103.4	104.2	104.9	104.7	105.4	107.7	109.9	113.4	118.9	124.7	120.6	118.4	112.0	161.4
125	98.9	100.6	103.2	102.9	102.4	103.2	102.1	102.9	104.9	107.4	109.9	112.7	118.7	124.9	122.7	119.7	111.5	162.0
160	98.4	99.1	101.4	101.6	101.4	100.1	102.4	103.2	103.6	106.2	109.7	112.9	117.7	122.4	122.9	120.9	110.5	161.0
200	99.1	100.6	101.4	100.6	100.1	101.4	100.9	101.6	102.1	105.9	109.6	113.6	120.4	122.1	119.4	118.4	109.0	160.3
250	99.6	101.1	102.1	100.9	101.4	100.6	100.1	101.6	101.9	106.9	110.4	113.9	123.2	123.7	120.1	116.1	108.0	161.8
315	96.9	99.1	101.9	101.4	101.6	99.1	100.9	100.9	100.4	106.7	110.4	114.4	121.9	123.4	119.4	113.6	106.0	161.0
400	96.1	98.9	100.9	100.4	99.9	100.4	101.1	99.6	100.6	105.4	109.4	112.9	118.2	120.1	115.9	112.6	104.0	158.0
500	96.1	98.9	100.4	99.6	100.6	100.1	98.6	99.9	100.6	105.4	109.2	113.7	118.2	119.9	115.9	112.1	101.0	157.7
630	96.1	100.6	102.1	98.9	98.4	98.7	98.1	100.7	101.4	104.2	107.7	111.7	115.9	116.4	112.4	109.6	99.0	155.3
800	94.4	99.4	101.7	98.2	97.9	98.9	98.9	101.2	101.9	103.7	106.7	110.4	113.9	116.2	111.9	107.9	97.0	154.3
1,000	92.9	96.4	99.4	95.9	94.9	97.1	97.1	99.4	100.1	101.9	104.4	107.4	110.9	114.9	109.6	105.9	94.5	152.2
1,250	90.6	94.1	96.6	94.9	94.4	95.1	95.9	96.6	98.4	101.7	102.1	103.1	108.9	110.9	106.9	102.9	93.5	149.2
1,600	88.1	91.1	93.6	93.6	92.9	94.1	96.1	97.7	99.4	101.4	99.4	100.6	106.9	110.7	105.6	101.4	91.5	148.2
2,000	87.1	89.9	92.4	92.9	93.1	94.9	96.4	97.6	99.9	102.1	97.4	100.9	105.6	107.1	103.1	98.1	89.5	146.4
2,500	85.8	88.3	90.6	91.6	91.6	93.6	94.8	96.3	99.1	101.1	97.6	99.4	104.9	105.9	101.9	95.9	88.0	145.4
3,150	84.8	87.1	88.6	90.1	91.6	91.4	93.4	95.9	98.4	99.9	98.7	99.7	103.4	104.4	101.4	93.9	86.0	144.4
4,000	83.4	84.4	84.7	88.2	88.2	89.2	91.0	91.7	95.2	95.4	97.0	98.7	101.4	103.9	97.1	88.1	84.5	142.4
5,000	80.8	81.4	81.2	85.3	84.6	85.9	87.4	88.3	91.1	92.1	94.6	96.2	100.1	102.4	94.4	88.9	81.0	140.4
6,300	79.1	78.8	76.7	81.9	82.9	82.4	83.8	84.7	88.0	88.0	90.0	92.7	98.6	100.4	91.9	86.4	78.0	138.0
8,000	77.3	76.7	73.8	80.0	80.4	79.5	80.8	81.9	82.6	85.2	86.9	88.9	98.4	99.9	89.4	82.6	73.5	136.9
10,000	72.0	70.3	68.2	74.7	74.2	72.8	74.3	74.2	77.2	78.5	81.1	85.9	95.4	97.2	88.1	79.1	70.0	134.0
	OASPL, dB																	
------	108.7	110.9	113.4	112.4	112.4	112.9	113.4	113.9	115.7	118.2	120.9	124.2	130.2	132.9	130.4	127.4	120.5	[a]170.8
	Perceived noise level, PNdB																	
------	115.4	117.8	119.5	119.2	119.5	120.1	121.1	122.4	124.3	126.5	127.3	130.6	136.7	138.8	134.8	131.2	122.3	-----

[a]Overall L_w.

TABLE 2. - ACOUSTIC MEASUREMENTS AND COMPUTATIONS FOR TWO-ENGINE OPERATION - Continued

(b) Military

One-third-octave-band center frequency, Hz	θ, deg																	L_W, dB
	0	10	20	30	40	50	60	70	80	90	100	110	120	130	140	150	160	
	Sound pressure level, dB (ref. 0.00002 N/m^2)																	
50	80.9	81.4	83.4	84.2	84.7	84.9	86.7	87.7	88.9	89.4	90.9	93.4	95.9	103.4	105.4	106.4	101.0	143.7
63	81.9	82.9	86.4	87.4	88.2	88.4	89.4	90.4	95.4	91.9	93.1	95.9	98.4	106.4	108.7	108.2	102.5	146.4
80	85.9	86.9	90.1	91.2	91.9	92.9	93.2	93.7	93.7	94.9	96.7	99.4	101.9	109.9	113.2	111.4	105.5	150.1
100	88.9	90.6	93.6	94.4	95.1	94.6	94.6	93.6	93.4	94.4	97.4	100.4	102.4	110.1	115.2	113.4	106.5	151.5
125	90.9	92.1	94.6	93.9	93.9	94.4	92.9	93.1	95.9	96.7	98.9	100.9	103.1	110.4	115.9	115.2	107.0	152.5
160	92.2	93.1	95.1	93.6	92.9	92.9	93.6	95.1	95.6	96.1	98.4	100.9	103.4	110.9	112.9	115.4	106.5	151.6
200	95.9	97.9	97.9	95.9	94.9	96.9	95.9	95.6	96.4	96.6	99.6	101.9	104.6	112.9	113.9	114.9	107.0	152.3
250	96.9	97.6	98.9	96.9	99.4	97.6	97.4	98.9	99.4	98.4	100.9	102.1	105.4	112.9	114.6	111.6	104.0	152.0
315	92.4	93.9	96.6	96.4	95.6	95.6	97.9	97.2	96.9	96.7	99.1	101.4	104.2	112.4	112.9	110.9	101.0	150.8
400	93.6	94.6	95.4	94.4	94.9	94.9	96.1	93.4	93.9	94.9	98.1	100.4	103.4	110.9	110.9	110.9	101.0	149.5
500	93.6	94.4	96.1	93.6	95.6	94.9	93.9	93.4	92.6	94.4	98.1	100.9	103.1	110.7	110.9	110.6	96.0	149.3
630	91.6	93.6	95.9	93.2	91.7	91.7	93.7	93.7	93.4	91.9	95.4	98.2	101.9	107.4	107.7	107.1	93.0	146.4
800	88.6	91.9	93.4	91.1	90.4	91.7	92.2	92.7	94.4	91.4	93.9	97.4	100.7	106.2	107.4	105.1	90.0	145.3
1,000	86.9	88.9	91.1	88.9	88.9	90.6	90.1	90.4	90.6	89.4	92.1	95.9	98.4	105.4	104.9	103.4	88.0	143.6
1,250	84.6	86.1	88.1	87.9	87.9	88.6	88.1	86.6	87.6	88.9	90.6	92.9	96.4	101.4	102.9	101.1	86.0	140.9
1,600	82.1	83.9	86.1	86.9	86.6	86.4	87.4	86.9	88.1	88.6	88.6	89.9	93.9	100.7	101.6	98.9	86.0	139.5
2,000	83.1	84.6	87.4	86.9	86.6	87.1	88.4	87.9	89.4	90.1	86.4	89.9	92.9	97.1	98.6	95.9	82.0	137.3
2,500	84.1	84.8	87.3	86.1	85.3	86.6	87.3	87.6	89.1	90.1	86.6	87.4	92.6	95.1	96.9	92.9	81.0	136.0
3,150	84.1	84.4	85.6	85.4	85.4	84.7	85.4	86.9	87.6	89.4	86.4	86.7	91.1	93.1	94.9	89.6	78.0	134.4
4,000	82.4	82.4	82.9	84.7	83.7	83.7	84.0	82.9	84.7	85.4	85.0	85.7	87.9	91.6	87.6	83.1	77.0	131.3
5,000	81.1	80.4	80.5	82.8	81.8	82.1	81.9	80.3	81.8	82.8	83.3	83.5	84.9	88.1	84.9	83.9	73.0	128.7
6,300	78.9	78.5	76.2	80.9	80.4	79.9	80.3	77.5	78.5	79.5	80.2	80.7	82.1	85.1	83.9	80.9	70.0	126.2
8,000	76.9	76.2	74.1	78.5	78.4	77.7	77.8	75.7	72.6	75.7	75.9	77.9	79.1	83.1	80.6	77.1	66.0	123.3
10,000	71.7	69.5	66.2	71.7	72.2	71.1	71.5	69.0	66.9	68.3	69.6	71.4	76.1	78.6	77.1	74.1	65.0	118.3
	OASPL, dB																	
------	103.9	104.2	106.7	105.2	105.9	105.9	106.2	105.7	106.9	106.7	109.2	111.4	113.9	121.4	123.9	122.9	115.0	[a]161.3
	Perceived noise level, PNdB																	
------	111.6	112.6	114.0	113.6	113.9	113.7	114.2	114.1	115.0	115.6	116.1	118.1	121.0	127.6	128.8	127.5	118.0	------

[a]Overall L_W.

TABLE 2. - ACOUSTIC MEASUREMENTS AND COMPUTATIONS FOR TWO-ENGINE OPERATION - Continued

(c) 83-percent rpm

One-third-octave-band center frequency, Hz	θ, deg																	L_w, dB
	0	10	20	30	40	50	60	70	80	90	100	110	120	130	140	150	160	
	Sound pressure level, dB (ref. 0.00002 N/m^2)																	
50	78.4	78.9	80.9	82.2	83.2	83.2	84.7	85.2	86.6	87.1	88.6	90.6	93.1	99.4	101.4	102.9	97.5	140.1
63	79.9	81.1	84.4	86.2	86.9	86.9	87.7	88.4	92.7	90.4	90.9	92.9	96.2	102.4	104.7	105.2	98.5	142.9
80	83.1	84.9	87.9	89.2	90.4	91.2	91.2	90.4	91.2	91.4	92.2	94.4	97.2	104.2	107.9	107.7	101.0	145.3
100	88.6	90.1	92.6	93.2	92.1	91.9	92.6	90.9	90.6	92.4	94.4	96.4	97.4	104.7	109.2	109.2	103.0	146.6
125	88.4	90.1	92.4	91.1	90.9	91.1	89.6	89.4	91.6	93.7	95.6	97.2	98.7	104.4	109.9	110.4	103.5	147.2
160	90.6	91.4	93.1	90.4	89.4	90.4	90.6	92.1	92.6	93.7	96.1	97.4	98.7	104.2	106.1	110.4	102.5	146.1
200	95.4	96.6	96.1	93.6	92.1	95.6	95.1	93.6	94.4	93.6	97.1	98.6	99.9	104.9	106.1	109.1	103.0	146.2
250	94.9	95.1	95.6	93.1	95.4	93.4	92.9	94.1	94.4	94.9	96.9	97.4	99.9	105.1	105.6	103.4	98.0	144.7
315	90.4	92.1	92.9	90.9	92.1	90.9	92.9	91.6	92.6	93.7	94.9	95.6	98.9	103.7	103.1	99.9	95.0	142.7
400	91.4	91.6	91.9	89.4	89.6	89.6	90.9	87.9	88.1	90.9	93.6	94.4	96.9	101.9	99.4	98.1	92.0	140.5
500	91.1	91.6	92.6	88.6	90.4	89.6	89.1	87.9	86.6	90.6	93.6	94.9	96.6	101.7	99.1	97.9	88.0	140.2
630	89.4	90.6	91.1	88.1	87.4	86.4	87.4	87.6	87.4	87.9	89.4	91.9	95.2	98.4	95.6	94.1	85.0	137.4
800	85.9	87.9	89.4	86.1	85.6	85.9	86.6	87.1	87.9	86.9	88.6	90.4	93.9	98.4	94.9	93.1	83.0	136.7
1,000	84.6	85.1	87.4	84.9	83.4	84.9	84.9	84.1	84.4	84.4	86.1	88.6	90.9	96.9	92.1	90.4	81.0	134.5
1,250	83.9	85.4	85.6	86.4	84.1	83.9	83.4	82.1	81.6	83.9	83.9	85.4	88.9	93.6	89.1	86.9	79.0	132.1
1,600	86.6	90.6	88.6	88.9	86.1	86.6	85.4	84.6	83.4	84.6	81.4	82.4	86.9	93.4	87.6	85.9	79.0	132.2
2,000	89.9	91.9	90.4	88.6	86.6	87.1	86.9	85.9	85.1	86.6	79.6	81.9	85.9	89.9	86.4	82.4	76.5	131.8
2,500	89.9	91.1	89.3	87.6	85.3	86.1	84.8	83.8	84.1	86.1	80.3	79.4	84.1	87.9	85.9	79.9	75.0	130.5
3,150	92.9	92.1	91.1	91.1	88.1	87.2	84.1	85.4	83.4	85.9	80.9	79.4	81.6	84.6	85.1	78.9	73.0	131.0
4,000	89.7	90.4	88.2	90.4	86.7	87.0	84.5	82.7	81.9	82.7	80.7	79.7	78.4	82.6	78.9	74.1	68.0	129.4
5,000	84.9	86.9	83.5	86.1	82.8	83.6	80.6	79.1	78.8	79.3	78.1	78.2	76.1	78.9	72.4	72.1	70.0	125.8
6,300	81.9	82.8	78.7	82.4	79.6	80.4	77.5	75.5	74.5	75.0	74.4	75.2	74.4	75.6	69.5	69.1	67.5	122.3
8,000	79.1	79.2	74.6	79.8	76.6	77.0	74.8	73.9	69.6	72.0	70.4	71.4	72.4	73.6	68.6	66.6	64.0	118.7
10,000	72.0	71.5	66.5	72.5	69.2	69.6	68.8	67.0	64.4	64.5	64.3	65.7	69.9	69.9	66.9	65.1	61.0	113.3
	OASPL, dB																	
------	103.4	104.7	104.4	103.2	102.2	103.2	102.9	101.9	102.9	103.7	105.4	106.9	108.7	113.9	116.4	117.4	111.0	[a]155.2
	Perceived noise level, PNdB																	
------	115.6	116.0	115.2	114.9	112.9	112.8	111.5	111.2	110.6	112.1	111.5	112.5	114.8	119.7	119.4	119.5	113.1	------

[a]Overall L_w.

TABLE 2. - ACOUSTIC MEASUREMENTS AND COMPUTATIONS FOR TWO-ENGINE OPERATION - Continued

(d) 59-percent rpm

One-third-octave-band center frequency, Hz	θ, deg																	L_W, dB
	0	10	20	30	40	50	60	70	80	90	100	110	120	130	140	150	160	
	Sound pressure level, dB (ref. 0.00002 N/m^2)																	
50	74.4	75.1	78.9	80.2	79.9	78.9	80.4	81.2	82.1	82.4	82.1	84.4	85.9	90.4	90.9	92.7	90.0	131.5
63	76.4	76.4	79.9	81.4	81.7	80.9	81.4	82.7	83.2	83.4	83.2	84.4	87.4	90.7	92.2	93.7	90.5	132.4
80	79.9	81.4	84.4	85.9	86.7	86.4	86.2	85.4	85.7	86.2	86.4	87.9	89.7	92.4	93.9	95.7	91.0	134.7
100	80.9	82.1	85.1	86.4	85.6	84.4	84.4	83.1	82.9	84.6	86.4	88.2	88.1	91.7	93.4	95.2	88.5	133.8
125	82.9	84.9	87.6	86.1	85.1	83.6	81.6	84.1	86.4	87.9	90.2	90.9	91.2	92.4	93.2	95.4	88.0	135.0
160	86.1	86.9	89.1	87.1	84.4	84.9	86.9	89.4	88.4	87.1	87.9	87.4	88.1	91.4	90.4	94.4	88.0	134.2
200	84.6	85.1	85.1	83.1	80.4	82.6	83.4	84.4	83.1	82.9	84.4	85.9	87.9	91.1	89.9	90.1	86.5	131.7
250	82.9	82.4	84.4	81.4	82.6	81.4	81.9	83.4	84.9	83.6	85.1	85.1	86.9	90.1	90.1	86.4	81.5	130.9
315	82.4	83.4	82.9	82.9	81.6	79.6	81.4	80.6	81.4	81.1	82.6	83.4	85.4	88.4	85.9	82.4	79.5	128.7
400	82.4	82.9	80.9	78.9	78.4	77.4	78.4	75.4	77.4	78.1	79.6	80.6	82.1	85.1	83.6	80.9	74.0	125.7
500	82.1	82.6	81.4	77.9	78.9	77.1	75.6	75.4	74.6	77.9	79.6	80.9	81.9	84.9	83.6	80.4	75.0	125.4
630	81.6	81.1	80.9	77.1	76.6	75.6	75.1	74.4	74.4	75.1	75.9	77.1	78.9	81.6	79.1	78.1	72.0	122.7
800	79.4	79.4	79.6	75.1	74.6	74.9	74.6	74.1	73.9	74.1	72.9	75.1	76.9	81.1	77.9	75.9	69.0	121.4
1.000	78.6	77.6	78.4	75.4	73.9	74.4	74.4	72.6	72.1	71.9	71.6	72.9	74.9	79.9	76.4	72.9	68.0	120.1
1.250	80.6	79.4	82.4	78.9	79.6	77.9	76.4	74.9	71.9	72.9	70.1	70.9	73.9	77.6	74.9	71.4	68.0	121.3
1,600	87.9	83.9	89.9	83.4	84.4	83.2	82.1	79.6	75.6	73.9	69.4	70.1	72.9	77.4	75.4	73.1	69.0	125.7
2.000	89.4	87.9	89.7	83.4	85.1	82.6	82.4	79.4	76.1	74.6	67.1	70.4	71.9	75.9	74.6	71.4	69.0	125.9
2.500	99.6	102.1	100.9	97.6	96.6	93.6	91.9	88.1	85.3	83.3	75.3	74.9	76.1	80.9	78.9	77.9	76.0	137.3
3.150	98.6	96.2	95.7	93.4	93.4	90.0	88.7	87.4	83.1	82.9	74.2	73.2	75.4	78.4	78.6	75.1	73.0	133.4
4,000	88.0	87.7	87.7	85.4	84.9	82.5	81.5	78.7	75.7	74.9	69.2	70.2	70.4	74.4	71.4	67.1	69.0	125.4
5.000	91.1	88.9	87.5	85.9	85.1	82.7	81.2	77.1	74.8	72.1	68.3	69.5	69.1	70.9	68.4	67.1	66.0	125.4
6.300	86.2	85.3	83.2	84.2	83.4	80.4	78.5	75.5	73.5	70.0	67.4	68.7	69.1	69.4	66.9	65.6	65.0	123.0
8.000	83.4	81.7	77.4	79.3	78.9	75.0	74.4	71.2	66.6	65.2	62.6	63.4	66.9	67.6	65.1	63.4	61.5	118.4
10.000	75.2	73.5	68.2	71.5	71.4	67.6	66.3	63.7	60.2	57.3	56.1	57.7	62.4	63.4	61.1	59.1	57.5	110.9
	OASPL, dB																	
------	106.2	104.4	103.9	101.4	100.7	98.7	97.9	96.4	96.2	95.9	96.9	97.2	98.2	101.2	101.9	103.7	99.0	[a]144.9
	Perceived noise level, PNdB																	
------	117.9	118.9	118.3	115.5	114.8	112.3	111.1	108.7	106.4	105.5	101.3	101.9	103.3	106.9	105.8	105.1	101.2	------

[a]Overall L_W.

TABLE 2. - ACOUSTIC MEASUREMENTS AND COMPUTATIONS FOR TWO-ENGINE OPERATION - Concluded

(e) 45-percent rpm

One-third-octave-band center frequency, Hz	θ, deg																	L_W, dB
	0	10	20	30	40	50	70	60	80	90	100	110	120	130	140	150	160	
	Sound pressure level, dB (ref. 0.00002 N/m^2)																	
50	68.9	70.6	73.4	75.2	75.4	73.6	73.9	74.9	75.6	75.6	74.9	75.9	74.9	77.6	75.4	76.4	75.5	120.7
63	68.9	69.9	71.9	73.4	74.2	72.9	72.7	74.4	73.9	74.1	73.9	74.4	78.7	78.4	74.1	76.1	76.5	120.5
80	69.9	71.9	74.1	74.9	75.4	75.9	75.4	75.4	74.6	73.9	74.6	75.7	75.1	78.1	76.6	77.9	76.0	121.0
100	71.4	73.1	75.1	75.6	77.1	76.9	75.6	74.4	73.1	74.9	77.1	79.4	79.1	81.4	80.4	81.1	78.5	123.2
125	69.4	71.4	73.6	71.6	72.4	72.6	69.1	70.6	73.1	75.6	78.1	79.2	79.4	81.4	78.6	80.9	79.5	122.6
160	70.4	67.6	72.9	71.9	70.4	69.1	69.1	71.4	73.4	74.4	76.1	77.1	77.6	79.9	76.1	77.6	79.0	120.9
200	72.6	73.9	72.9	71.4	67.9	68.9	69.4	70.9	69.6	69.4	74.1	75.6	72.6	79.6	77.1	73.1	80.0	119.7
250	74.1	75.4	73.6	69.6	70.4	68.9	68.4	67.1	68.4	67.1	69.9	71.9	73.4	77.9	77.1	72.6	77.0	118.1
315	74.9	76.4	73.9	72.6	72.1	69.1	69.9	68.4	68.9	67.1	70.9	72.1	73.4	78.4	74.4	76.9	76.0	118.5
400	76.9	76.9	73.4	72.4	71.4	70.9	70.9	66.9	69.1	68.4	69.4	72.4	74.4	77.1	76.1	75.9	76.0	118.4
500	76.6	76.6	74.1	71.4	71.9	70.6	67.6	66.6	65.6	67.9	69.4	73.1	74.1	76.9	76.1	75.4	74.0	118.0
630	75.1	74.6	74.6	70.4	69.1	68.6	66.9	65.6	65.6	67.6	64.6	67.1	68.1	69.1	70.9	72.9	74.5	114.9
800	73.4	73.9	72.6	68.9	67.6	67.4	66.1	64.9	64.4	63.6	62.9	65.4	67.4	69.9	70.1	70.1	70.0	113.2
1,000	73.4	72.9	72.6	68.4	67.1	68.9	67.1	65.6	64.9	64.4	63.4	66.4	67.1	70.4	68.4	68.9	72.0	113.4
1,250	74.9	75.4	75.1	73.1	72.4	72.4	69.1	67.4	66.6	65.4	63.6	65.4	65.6	69.6	68.1	67.6	71.5	114.9
1,600	77.6	74.9	73.6	74.9	75.6	74.1	73.1	70.6	68.4	66.6	61.9	63.6	64.9	70.4	68.9	64.9	71.0	116.3
2,000	95.4	94.9	92.7	93.9	94.9	92.7	88.9	86.2	81.4	79.6	72.6	73.0	72.1	80.4	77.9	72.4	78.5	133.5
2,500	90.4	88.6	86.6	87.1	85.9	85.1	83.3	80.3	77.8	76.1	68.6	69.6	69.1	74.1	72.9	69.9	74.0	126.6
3,150	91.6	88.1	87.7	85.7	83.4	80.4	78.6	76.9	73.9	73.4	66.7	67.2	69.1	70.9	70.1	70.1	72.0	124.6
4,000	85.0	84.4	84.7	83.7	81.4	79.7	78.7	74.9	72.7	71.2	66.5	68.0	68.9	69.9	64.9	63.6	72.0	122.6
5,000	82.1	81.4	79.5	82.6	77.9	77.2	76.1	72.6	71.8	68.8	65.6	68.0	70.1	70.4	65.9	68.1	70.5	120.2
6,300	80.9	80.1	76.7	79.4	76.4	73.9	72.8	69.2	68.5	65.5	62.2	65.2	68.6	70.9	65.1	66.6	67.5	117.6
8,000	74.9	74.7	69.4	74.0	71.2	68.8	67.6	65.5	62.1	61.0	58.9	60.4	66.4	70.4	62.9	63.4	63.5	112.9
10,000	67.2	66.0	60.0	65.5	63.2	60.6	60.3	58.0	54.7	52.8	52.3	54.5	59.4	62.2	54.6	55.9	57.0	105.3
	OASPL, dB																	
------	100.4	96.4	95.9	96.2	95.9	94.2	91.9	89.7	87.7	87.2	86.4	87.4	87.2	90.9	89.1	89.4	89.5	[a]136.9
	Perceived noise level, PNdB																	
------	111.7	111.0	109.3	109.8	109.7	107.8	105.1	102.7	99.6	98.3	94.2	95.5	96.0	101.0	98.5	96.5	99.8	------

[a]Overall L_W.

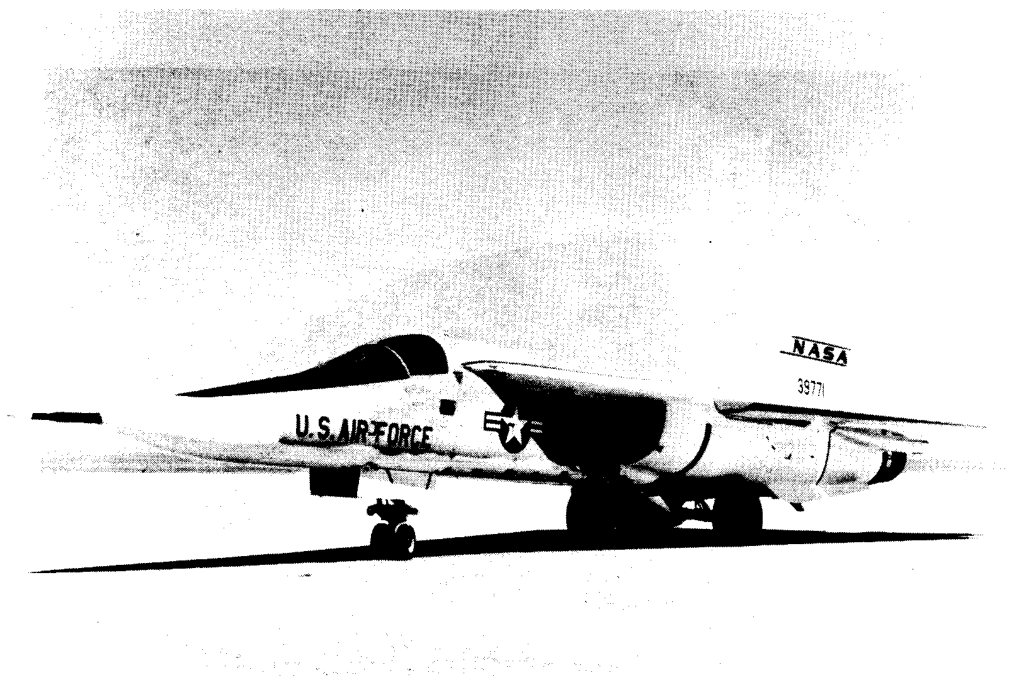


Figure 1. F-111A airplane. E-20273

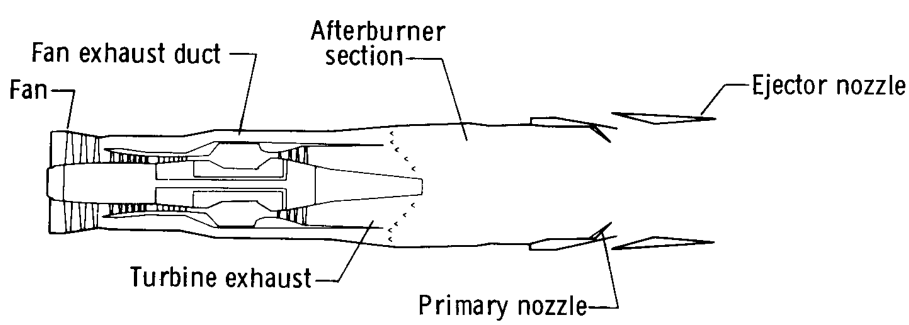


Figure 2. Sketch of TF30 engine.

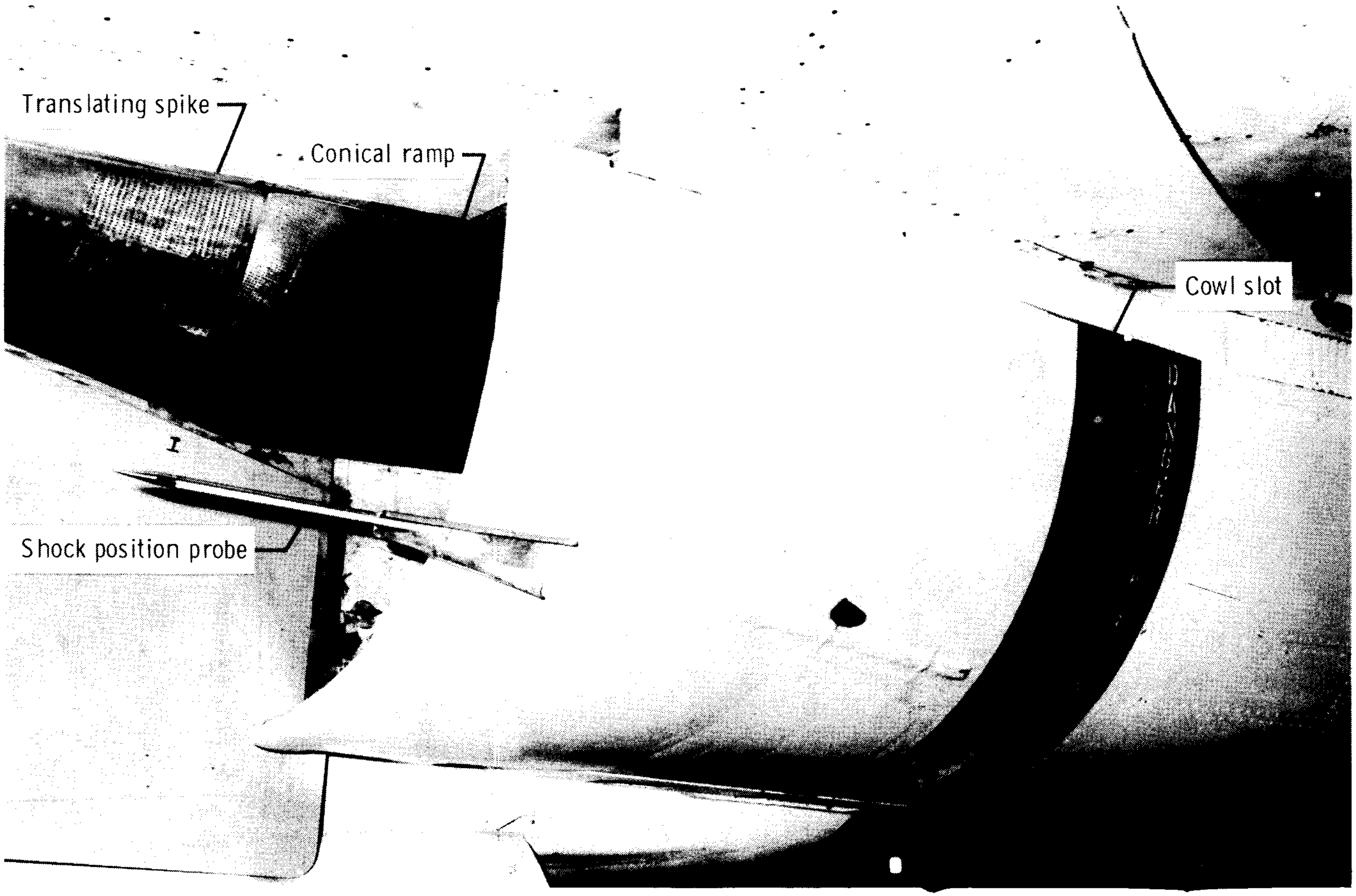


Figure 3. F-111A inlet. E-21375

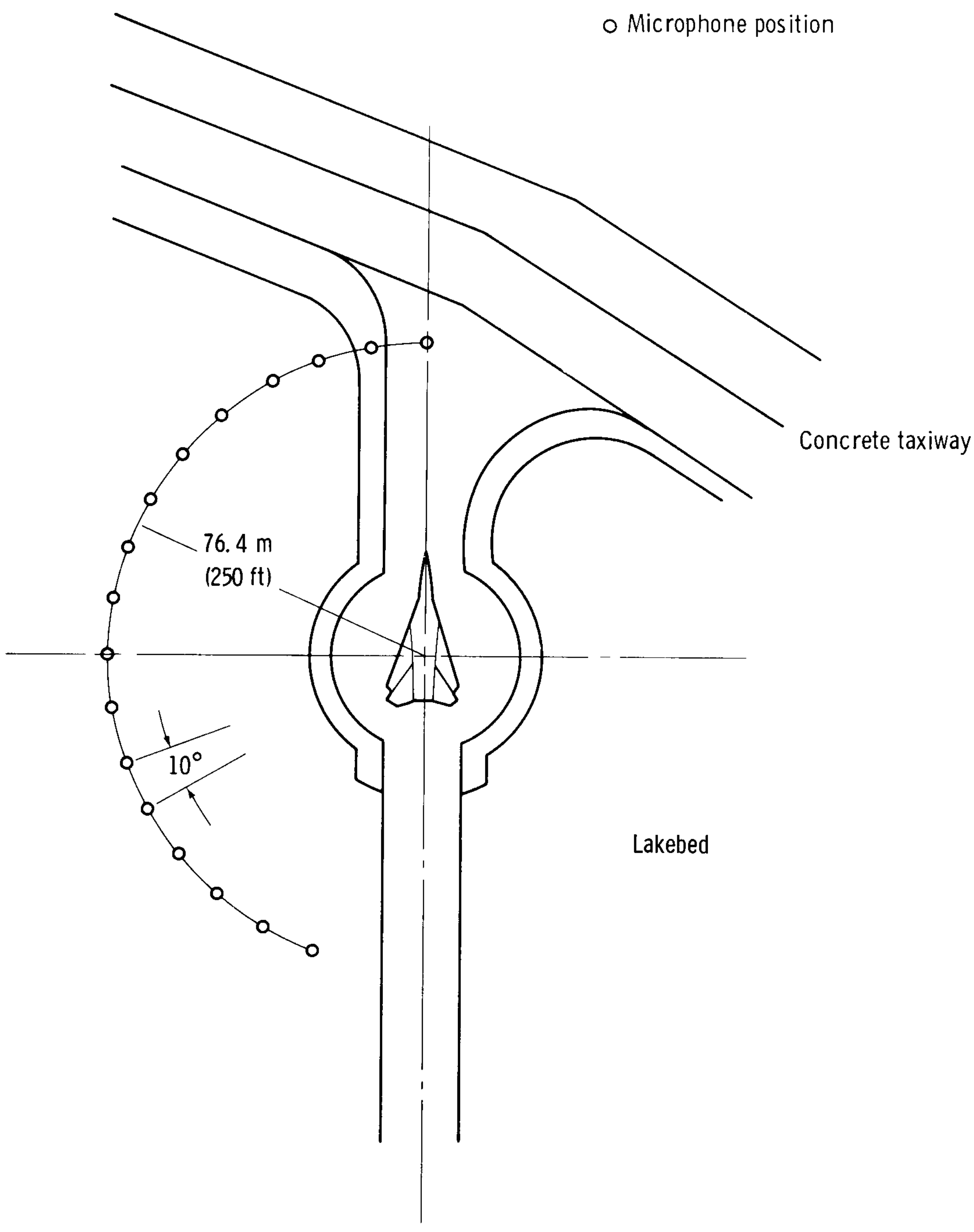
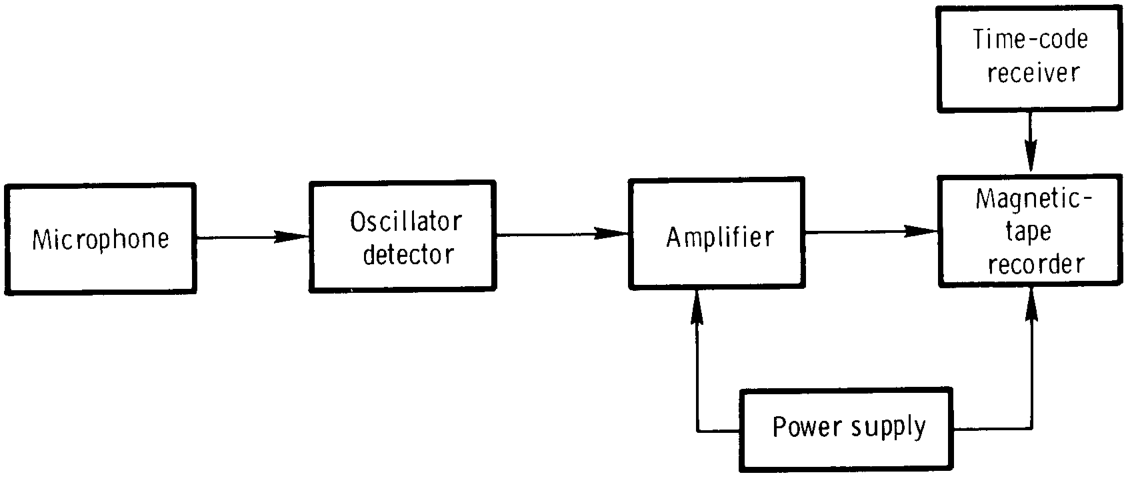
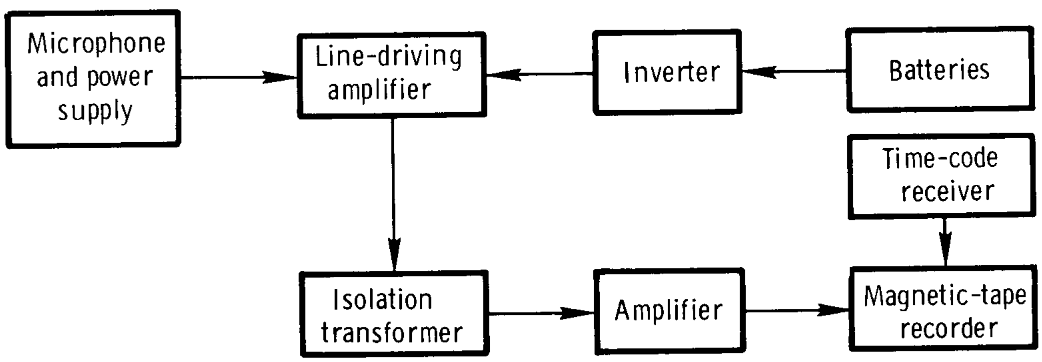


Figure 4. Microphone locations around F-111A airplane.



(a) For microphone positions 0° to 110°.



(b) For microphone positions 120° to 160°.

Figure 5. Block diagram of data acquisition system.

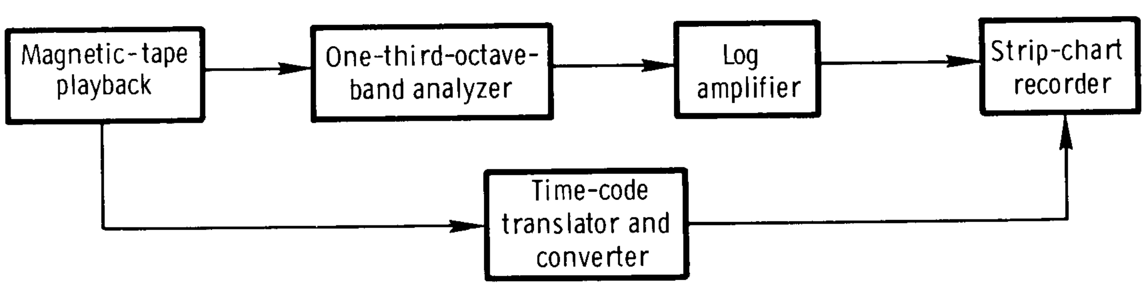
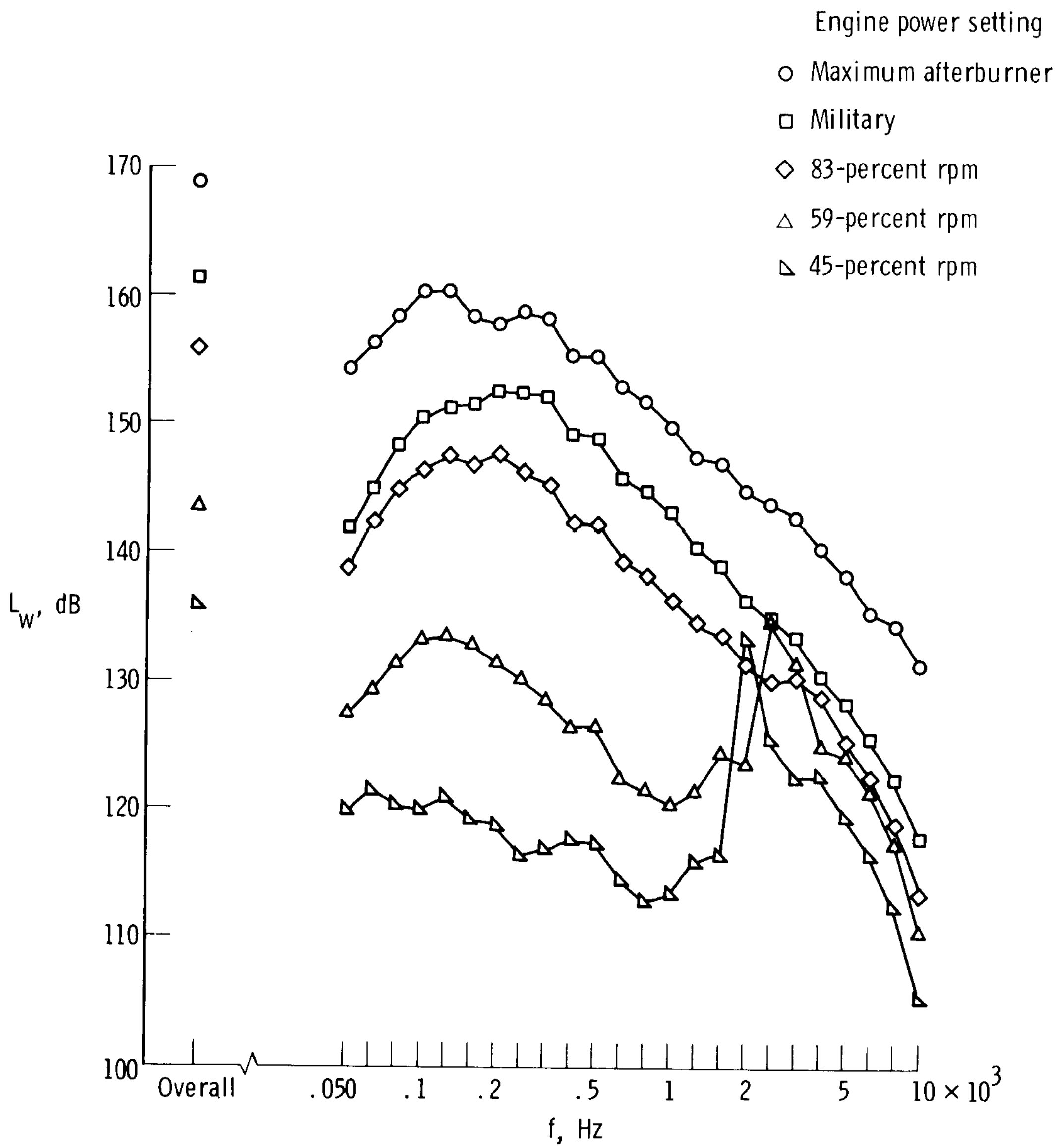
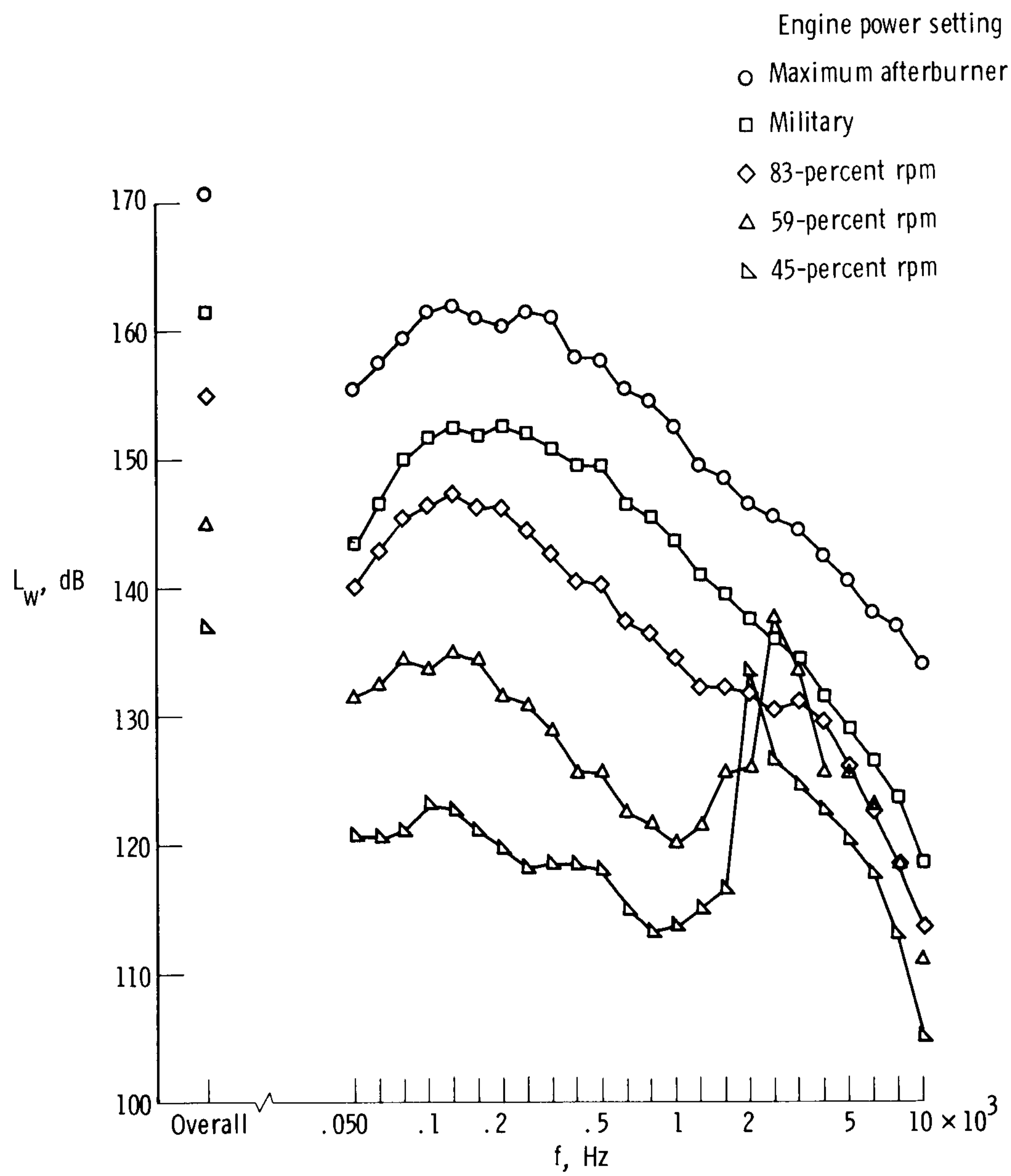


Figure 6. Block diagram of data reduction system.



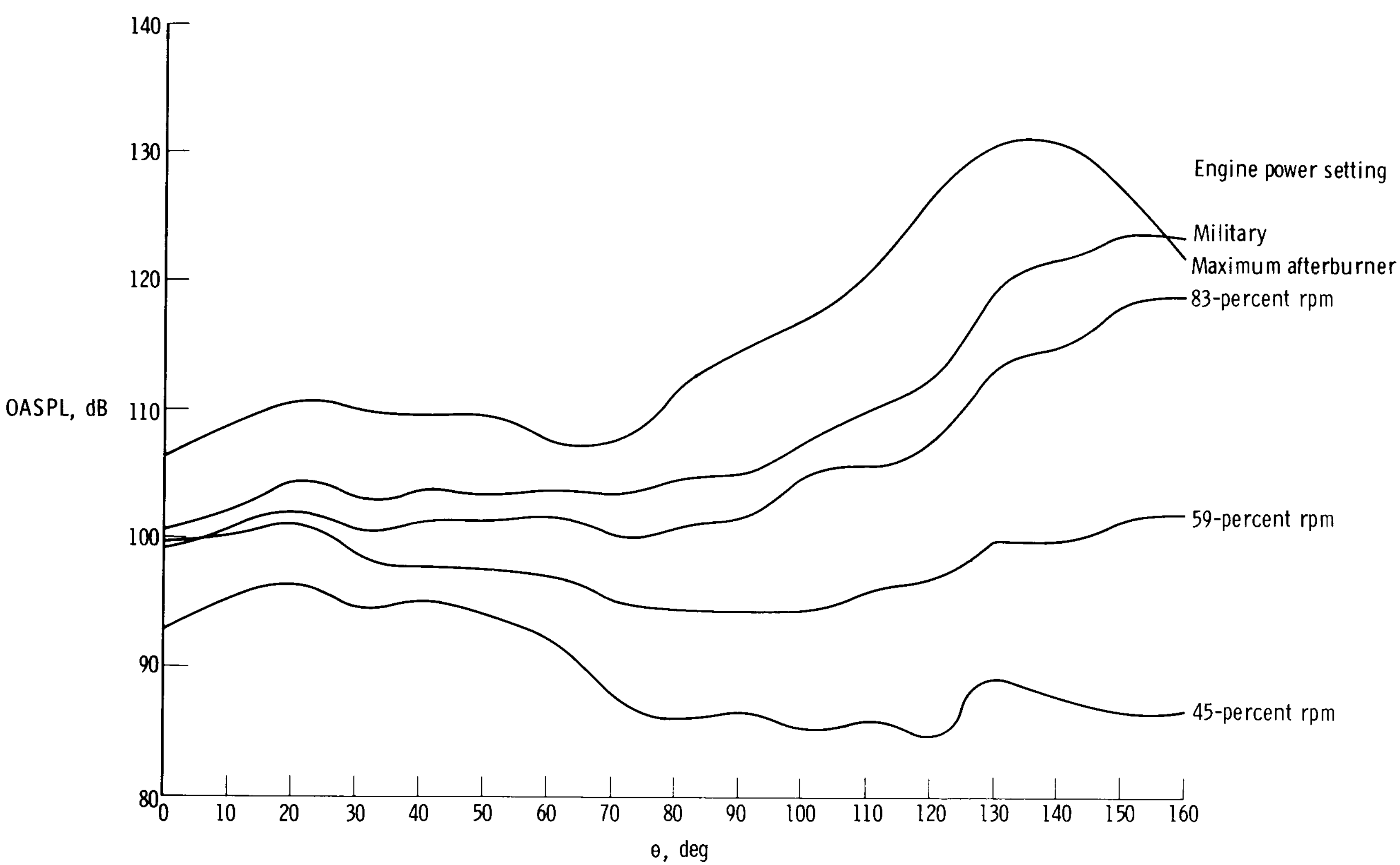
(a) One-engine operation.

Figure 7. Sound power spectra for F-111A airplane during ground operation at several engine power settings.



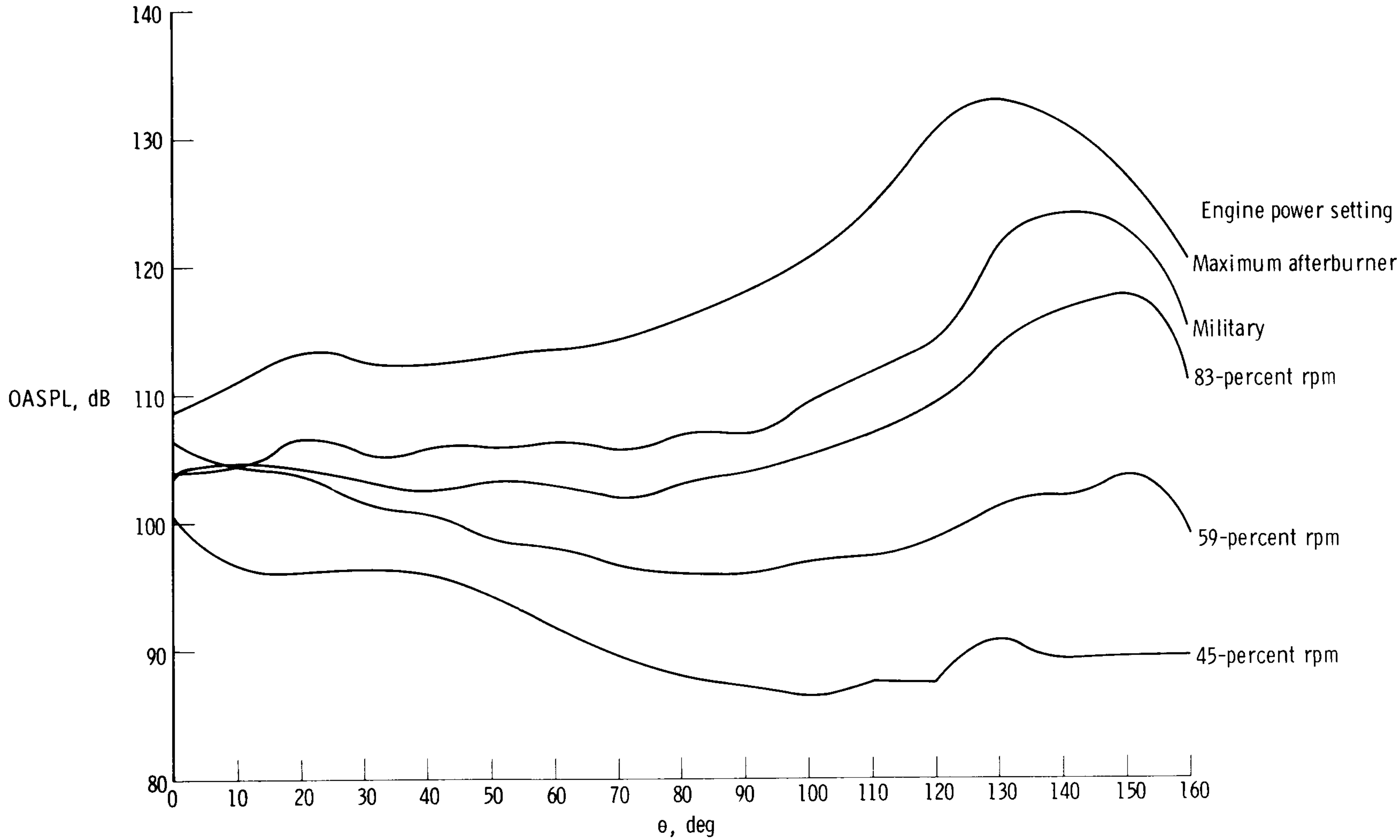
(b) Two-engine operation.

Figure 7. Concluded.



(a) One-engine operation.

Figure 8. Directional patterns of F-111A overall sound pressure levels at 76.4 meters (250 feet) for several engine power settings.



(b) Two-engine operation.

Figure 8. Concluded.

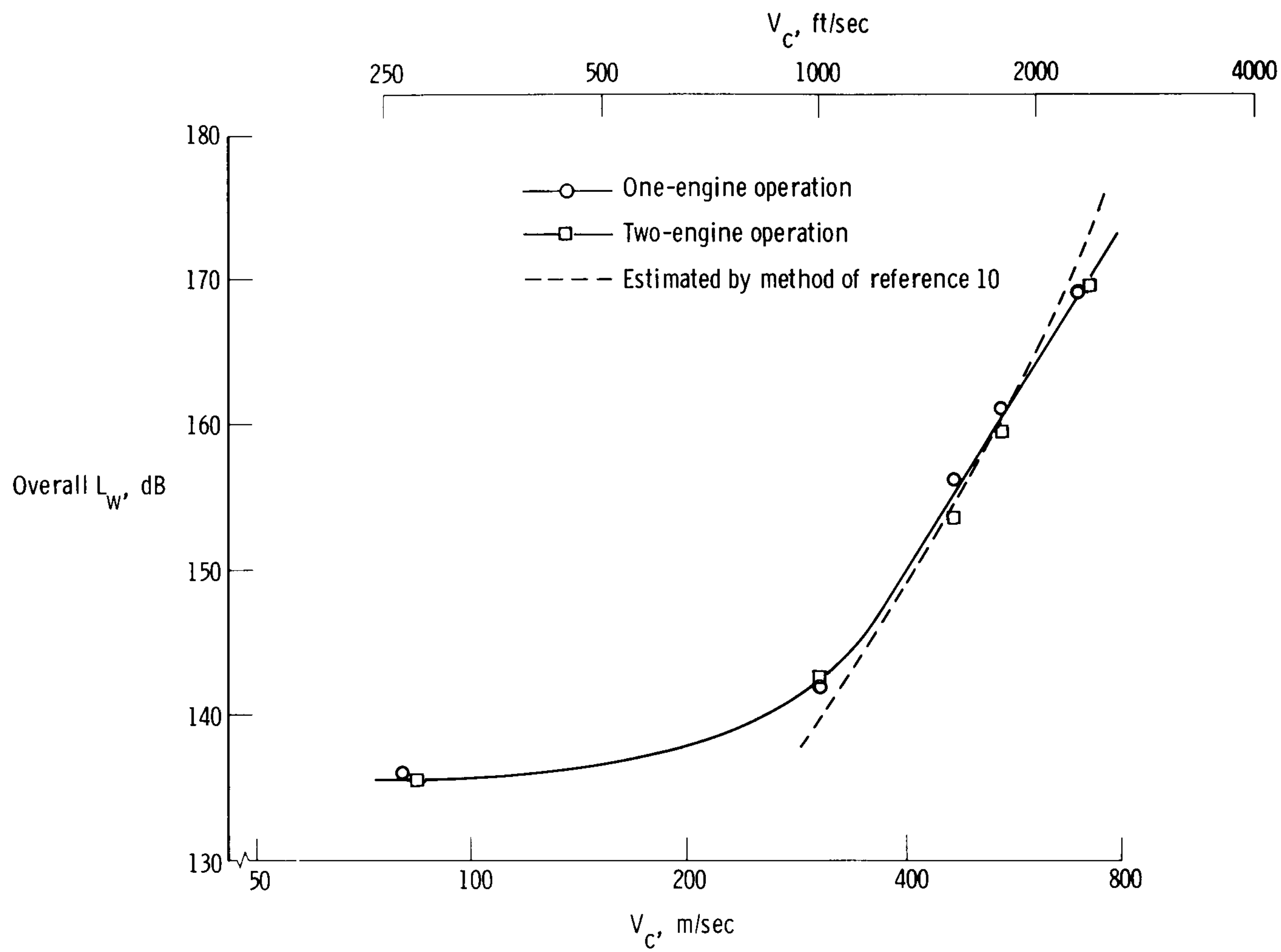
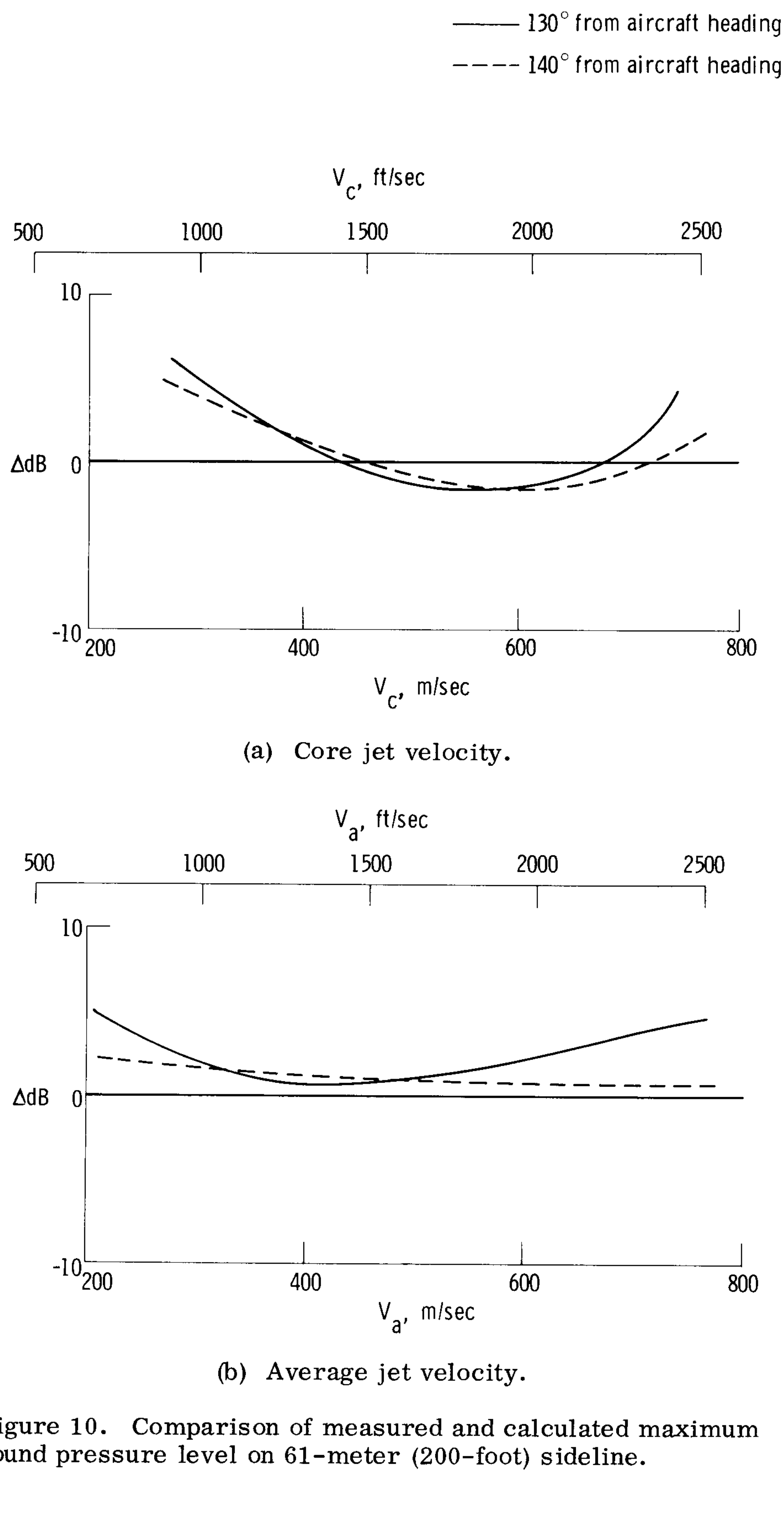


Figure 9. Total sound power generated by F-111A airplane as a function of core jet velocity.



(a) Core jet velocity.

(b) Average jet velocity.

Figure 10. Comparison of measured and calculated maximum sound pressure level on 61-meter (200-foot) sideline.

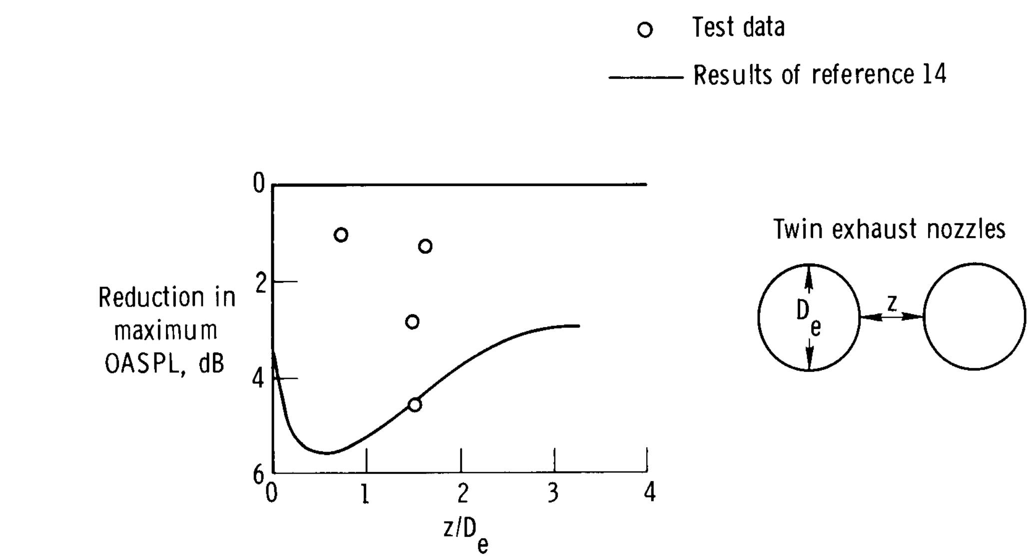


Figure 11. Maximum noise attenuation in horizontal plane as a function of jet exhaust separation relative to a nozzle of the same total area.

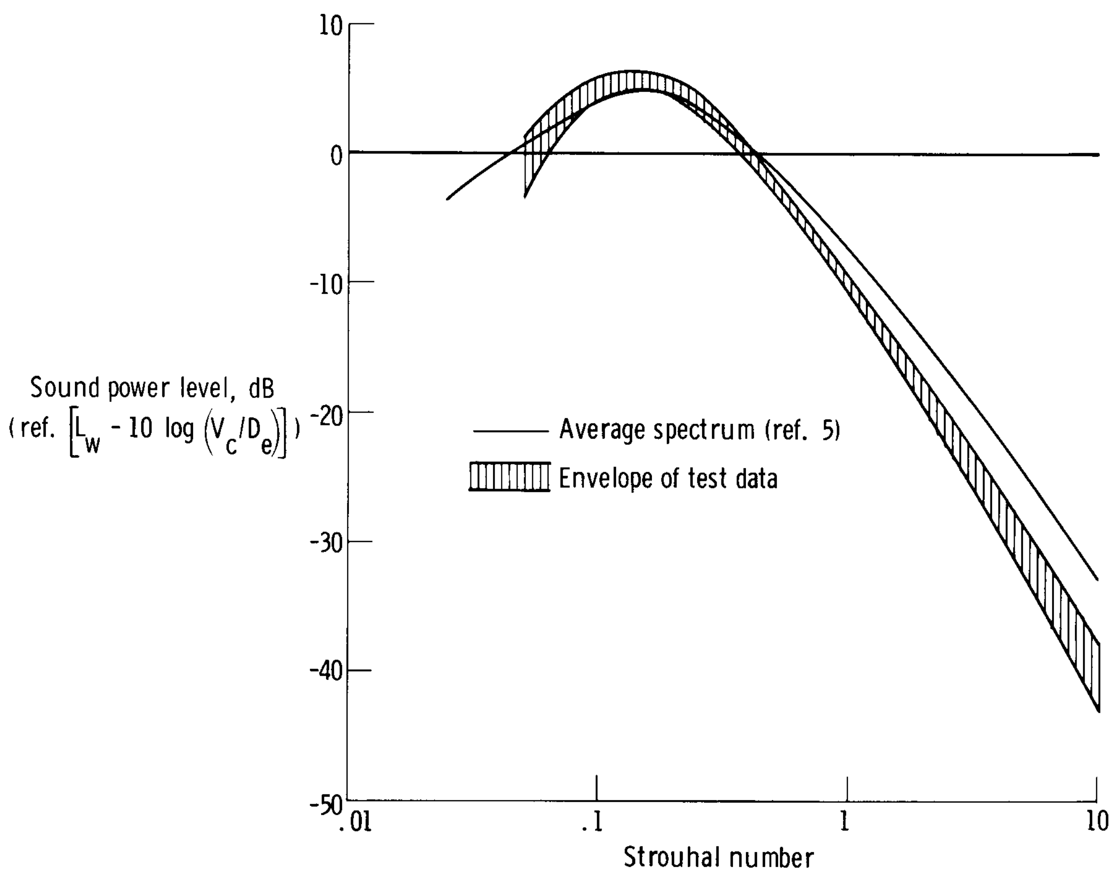
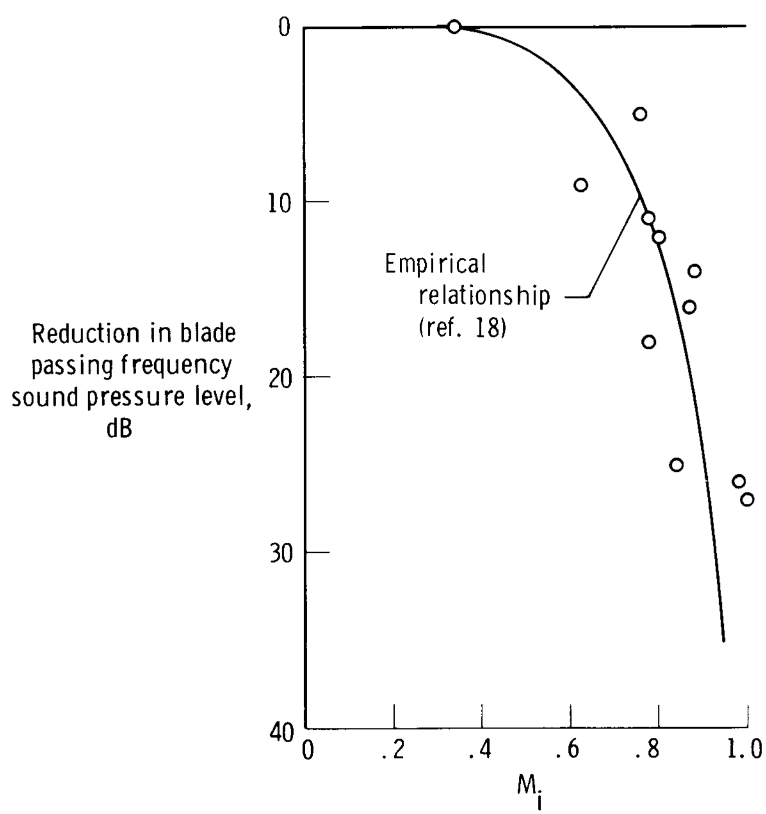
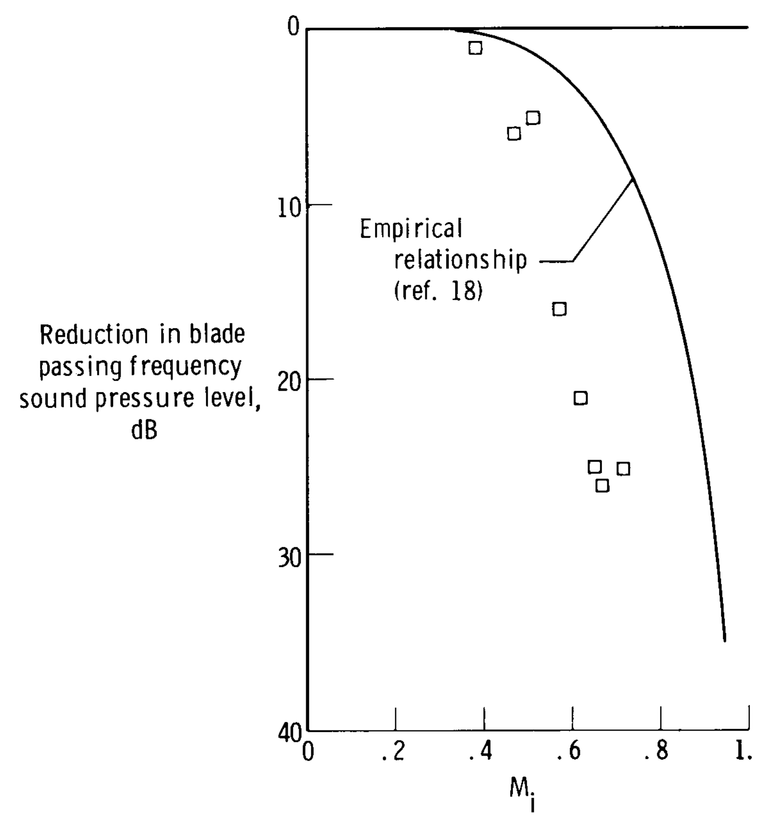


Figure 12. Normalized sound power spectra for one- and two-engine operation at three engine power settings.



(a) Cowl closed.



(b) Cowl open.

Figure 13. Reduction in blade passing frequency noise as a function of inlet Mach number at a position of 0° and 76.4 meters (250 feet).